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Innovation in the Mineral Industry: Opportunities and Strategies for Canada

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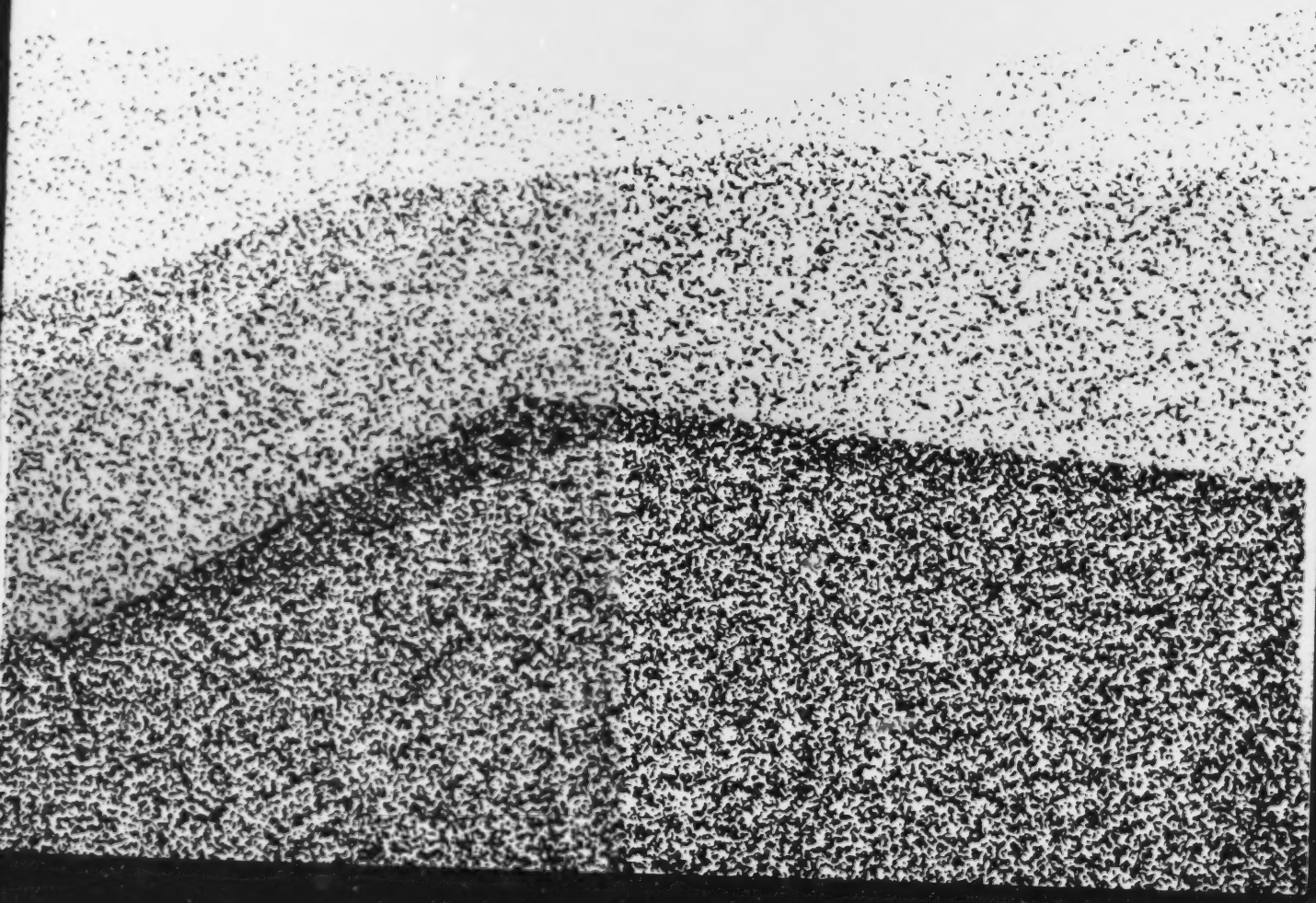

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INNOVATION IN THE MINERAL INDUSTRY: OPPORTUNITIES AND STRATEGIES FOR CANADA

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FOREWORD

This study was originally prepared under contract to MOSST, as part of its review of technology opportunities in the resource sector.

Due to constraints of time and the broad range of questions and issues raised by MOSST in its terms of reference, the work is based largely on existing literature. In addition, individuals in both private and public-sector mineral organizations have been very generous in sharing their ideas and concerns on this topic with us, and we are grateful for their interest and help. In particular, we would like to thank David Gladwin of EMR, Walter Curlook of Inco Ltd. and Jeff Jeffery and Trevor Jubb of CANMET for their extensive written commentaries on the draft text. However, we accept responsibility for the facts and interpretations presented.

The views expressed are those of the authors, and do not necessarily represent the views of the Centre for Resource Studies or its sponsors.

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SUMMARY

OBSERVATIONS

Maintaining leadership in important areas of technological innovation will be an essential ingredient in efforts to protect and maintain the international competitive position of the Canadian mineral industry. Unfortunately, at the present time, R&D and innovation are seriously underfunded by all but a few mineral companies. The underfunding is most acute for methods and equipment development in mineral exploration and mining, and for new materials and product development.

Compounding the problems of underfunding are a variety of contraints and barriers that reduce the effectiveness of the present R&D and innovation efforts. These include:

- organizational and attitudinal factors in the industry;
- administrative and other features of government support programs;
- a lack of communication and cooperation among and within the various companies, government agencies and university departments with interests and capabilities in mineral R&D and innovation;
- the lack of an indigenous mineral-industry equipment manufacturing capability, a lack that has been fostered to a significant extent by neglect on the part of mineral companies and government support programs.

The potential opportunities for innovation far exceed the capabilities of the financial and human resources in the Canadian mineral sector. Nevertheless, given Canada's needs and present level of expertise, there are significant opportunities for Canadian technological leadership, particularly in geophysics, continuous mining, and some aspects of physical metallurgy. However, improvements will be needed in the allocation and effectiveness of the available resources. Areas for improvement must include funding levels, funding focus, communication, cooperation, and risk-sharing mechanisms.

RECOMMENDATIONS

Short, medium and long-term elements of a proposed technology strategy are briefly outlined below. All the elements should be pursued immediately. The time factors refer to when results can be expected.

Short-term results: technology transfer strategy.
The strategy should place its emphasis on obtaining state-of-the-art technologies, from any available source, to improve the competitiveness of Canadian producers. This task requires the establishment of Canadian industrial intelligence networks and technology transfer mechanisms. Financial and practical support for the demonstration and commercialization of promising Canadian-developed technologies should be increased.

Medium-term results: development of domestic equipment manufacturing and technological capability.
Leadership cannot be maintained with second-hand technology. Applied research and development to explore new directions will be essential. Cooperative and joint-venture activities in R&D, demonstration, and commercialization should be encouraged, as well as technology transfer between organizations. There should be direct links between the industry and its equipment suppliers.

Long-term results: strength in basic, strategic, and long-term applied R&D.
For the long term, the strategy must aim at maintaining a strong competitive position and technological leadership across a broad range of minerals and mineral products. To maintain such a position by the end of the century, even within selected areas of specialization, Canada must have substantial research programs in place by the end of the current decade, including basic research programs which are over and above the R & D strategies discussed here. Interdisciplinary research, and the emerging technologies which generally are outside the traditional fields of mining and metallurgy, should be key elements of this long-term strategy.

Chapter 1. INTRODUCTION

PURPOSE

The Canadian mineral industry - from exploration through to the production of primary products - is facing severe economic problems. The sources of difficulty are numerous and have been documented and discussed extensively in recent years. They include:

- increased competition from new mineral producers in other countries with a wide variety of comparative advantages;
- prices for metals which have remained stagnant or even declining in real terms over the long term, while the costs of most production inputs have escalated, sometimes at alarming rates;
- short-term price instability that often exceeds the variations in other resource and manufacturing sectors;
- long lead times and high capital costs for new developments, resulting in very large increments in both capacity and debt load that have come on stream at just the wrong stage of change in mineral demand;
- long-term decline in growth of mineral demand, due for example to substitution, down-sizing, and leveling off of growth rates in developed countries;
- a very low level of R&D intensity in the mineral industry, compared to other sectors, and compared to metal producers in some competing countries, and a resulting relative decline in productivity that is just beginning to be addressed and reversed.

Contrary to widely-held views and classical economic theory, declining ore grades are not yet among the sources of difficulty for the Canadian industry.

How can these difficulties be overcome, and the economic health of Canada's mineral industry be restored? Canada exports most of its mineral production in relatively low-value form, as concentrates and primary metals, and will continue to do so, since production capacity far exceeds domestic requirements. Prices for Canada's mineral products are determined in international markets and there is little that can be done by Canadian producers or government policies to affect prices or demand levels. The only area subject to significant control within Canada therefore is production costs.

There are a number of avenues for cost cutting which, like the sources of difficulty, have been widely addressed in recent years. They are aimed at improving the productivity of the active participants in all levels of industry, and include:

- rationalization of the industry, through closure of those operations which are marginal or operating at a loss;
- more small-scale and high grade deposits, with smaller capital cost requirements and shorter lead-times for putting into production;
- more favourable exchange rates and terms of trade, cutting costs of the industry's import requirements and improving international prices in Canadian dollar terms;
- reduced unit production costs through application of technological innovation in methods and equipment.

This study examines the last-mentioned aspect only, looking at a number of areas of technology which are applicable to the major fields of activity of the mineral industry: i.e. to exploration; mine design and development; mining; and metallurgy. The study looks at technology with a view to drawing conclusions about the potential of various technologies for lowering production costs and improving productivity in the industry, and about means of realizing the opportunities offered by these technologies. It also looks at existing levels and sources of R&D funding and innovation effort. Recommendations are made for both the private and public sectors which are intended to increase, and to improve the effectiveness of, innovation efforts in the mineral sector, as a means of improving the long-term competitive position of the Canadian mineral industry.

SCOPE AND METHODS

The mineral industry for the purpose of this study comprises all stages of the mineral production cycle, including exploration, mine design, development, mining, extractive metallurgy and physical metallurgy. It excludes oil and gas, and gives only incidental attention to industrial minerals.

Research and development can be divided into three aspects:

- basic research, which is oriented toward the discovery and understanding of new phenomena;
- strategic research, which is generally described as "mission oriented";
- applied research, which applies the findings of basic research to specific problems.

Most efforts at technological innovation are directed at and found within the category of applied research. However, this generally leads only to incremental advances in technology. Major innovations require both the fundamental understanding provided by basic research and the new approaches and syntheses of supporting technologies that are most likely to arise in strategic research.

Chapter 2 sets the scene for the discussion of R&D opportunities and strategies with background information on the Canadian mineral industry, its long-term trends, economic impact, organization, and special problems. It is more detailed and wide-ranging than might be expected in a study of this sort, but is designed for readers who are not familiar with the mineral industry, its role in the economy, its long-term trends, and its special characteristics and problems. Much of the information was assembled in response to specific questions raised by the Ministry of State for Science and Technology (MOSST) in commissioning the study.

Chapter 3 reviews the present level of R&D funding and activities in the Canadian mineral industry, with an emphasis on federal activities and on the few companies with major R&D programs. Chapter 4 gives details on several areas of emerging technology which are of special interest to MOSST, because they may represent areas of common interest to several or all resource sectors.

Chapters 5 to 10 look at current technology in the various stages of mineral production, and at opportunities for significant breakthroughs in each of the stages.

Chapter 11 offers the authors' observations on a variety of issues including current research efforts and barriers to innovation in the industry.

Chapter 12 offers the authors' recommendations for actions that will enhance the rate of technological innovation in the short, medium, and long term, and will help to improve the long-term competitive position of Canadian mineral sector.

Information on the mineral industry and on R&D activities was obtained for the most part from published sources, particularly from Statistics Canada, EMR, The Mining Association of Canada, company annual reports, and trade and technical publications. Information and opinions on opportunities for and constraints to innovation were obtained from published sources, particularly trade and technical publications, and from conversations and interviews with individuals in the industry, in university departments, and government organizations.

The authors approached the wide variety of technical topics as generalists, and make no claim to having in-depth knowledge or understanding of all the latest advances or possibilities in each stage and activity of

the mineral production cycle. It is hoped that the overview and the examples used, however, provide useful insight into trends and developments that can contribute to constructive R&D strategies for the sector.

EXPECTATIONS FOR TECHNOLOGY

Technology, technological innovation, and high technology are widely viewed as holding the solutions to all the ills of mankind, if correctly applied. Unfortunately, expectations are often unrealistic. In this section, we will look very briefly at the role that technology change might be expected to play in resolving the problems of the mineral sector.

In exploration, technological advance in this century and even in the last few decades can be described as truly revolutionary. New techniques of gathering and interpreting information, and new concepts of the formation of mineral deposits, have given explorationists the capability to search far below visible outcroppings of mineral occurrences, and find them at considerable depth below the surface. Exploration also appears to offer the potential for future revolutionary change. Improvement of existing techniques and theories and development of new ones can lead to the opening of whole new horizons at depth. There is no reason not to expect the discovery of a whole new generation of deposits, successors to remarkable ones like the Sullivan mine, or Kidd Creek, or Dome's gold mine, at depths that are presently inaccessible to exploration. This will be of great importance in preserving the Canadian industry in the long term, by maintaining a continuing supply of competitive high-quality reserves.

In mining, change has been much more gradual and incremental. Underground hard rock mining and surface mining employ methods and equipment that have evolved step-by-step and that can be recognized as new generations of those in use in the 1930s. These improvements unquestionably led to enormous advances in productivity in terms of tons/manshift, although the rate of improvement seemed to drop off in the 1970s.

In the 1980s, as a result of serious economic difficulties, productivity improvement in mining has become a driving force. It has led to massive cuts in staff, both production and head office, to new approaches to mining methods, new developments in explosives, drilling, materials handling, and energy conservation efforts. These initiatives have led to productivity improvements that are significant, but that cannot be described as revolutionary.

For example, the major innovation in approach to underground mining is the trend towards bulk mining methods. While extremely effective where it is used, its useful application is, at present, largely limited to those operations in Canada with relatively large capacity and suitable deposit configuration. The same can also be said for efforts to develop continuous mining methods, which are not likely to be cost-effective for most smaller operations or for mines with narrow, faulted vein deposits for some time to come.

In beneficiation, particularly for base metals, approaches have changed little in recent decades, although there have been significant improvements in established techniques of grinding and separation. The major area for improvement here is the long-overdue application of automatic process control. Another is the development of advanced separation techniques. Unfortunately, the vast majority of Canada's existing mills are small, old, and cash poor, and unlikely to join in the benefits from automation and other major new approaches. Only larger plants and new mills will have sufficient incentive to pursue this type of innovation.

Extractive metallurgy has seen tremendous changes in this century, and comes closest to matching exploration in terms of the impact of technological innovation. Improvements have led to recovery of metals from low-grade and complex ores, and recovery of a whole range of new metals. Hydrometallurgy offers potential through developments such as ion exchange, solvent extraction, and biohydrometallurgical techniques which will improve volume and quality of recoveries, while reducing both costs and environmental pollution. Pyrometallurgy has advanced rapidly, for example towards closed-vessel continuous smelting that provides improved control of purity, higher metal recoveries, lower energy costs, and improved environmental protection. Unfortunately, opportunities for the application of new technologies in extractive metallurgy are constrained by the existing overcapacity in smelting and refining facilities.

Because Canada exports so much of its mineral production in crude or primary fabricated form, it has been involved very little in the recent revolution in new materials that is a key area in maintaining markets for mineral products. This was not always so; in the past, Inco and Cominco have been world leaders in this type of development, and Alcan's position in the field is still strong. Interest in this area is growing, but it too offers limited opportunity for Canadian mineral producers, because of the relative small volumes of raw materials involved and Canada's lack of comparative advantages (largely but not exclusively market-related) in the high-value-added aspects of the industry.

This somewhat pessimistic survey of technology potential is not meant to imply that the Canadian mineral industry does not need to pursue tech-

nological innovation with the greatest possible vigor, or that government policies should not support and encourage such activities. On the contrary, innovation is absolutely essential to the continued survival of the industry. However, technology does not offer a "quick-fix" solution that can single-handledly resolve all of the industry's problems.[1] Productivity improvements as a whole, outside of certain individual operations, will be gradual, constrained by a variety of obstacles - organizational, financial, and attitudinal - within the industry. The more revolutionary advances, for example in exploration or continuous mining, will take at least a decade to affect the industry's overall cash flow and competitive position. Evolutionary changes can be implemented more quickly, but will have only marginal effects on overall productivity and unit costs. Technological innovation, while essential, must be supported by a wide range of other management and government policy initiatives that will ensure its rapid and effective applications to the mineral industry, if Canada is to continue to benefit from its rich mineral endowment.

A TECHNOLOGY FRAMEWORK

Core Technologies

The mineral industry employs a broad range of technologies. A number of these, which we will refer to as "core" technologies (shown in bold in figures 1 and 2), may in some cases be unique to the industry, and are at the heart of the business. Such technologies include exploration technology, mining methods and processes, pyrometallurgy, and hydrometallurgy. While there is some degree of interaction between these technologies, they essentially evolve and change independently. There is a significant incentive for mineral producers to carry out research and development in these technologies, and this is where their R&D is focused, to the extent that it exists. Suppliers of the physical aspects of these technologies are frequently completely focused on mineral firms for their business.

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1. This view is shared by J.R. May, director of the Australian mineral industry research organization AMIRA, who estimates that more than 25 percent of mining costs are totally unaffected by technology. He goes on to say that, even for the remainder, technology can bring only modest and incremental cost improvements, and that "technological change is no panacea for the survival of the industry". J.R. May, "New Technology: Do We Need It?", Changing Gears, 3rd CIMM Mineral Economics Symposium, Toronto, 1985.

ROBOTICS	EXPLOSIVES	PROCESS CONTROL
MATERIALS HANDLING	MINING ROCK MECHANICS	CONSTRUCTION MATERIALS
BIOTECHNOLOGY	COMMUNICATIONS	ELECTRICAL EQUIPMENT

Figure 1. Mining: Core and Peripheral Technologies

ROBOTICS	INSTRUMENTATION	PROCESS CONTROL
MATERIALS HANDLING	PYROMETALLURGY HYDROMETALLURGY	MICROBIOLOGY
CONSTRUCTION MATERIALS	COMBUSTION	REFRACTORIES

Figure 2. Extractive Metallurgy: Core and Peripheral Technologies

Peripheral Technologies

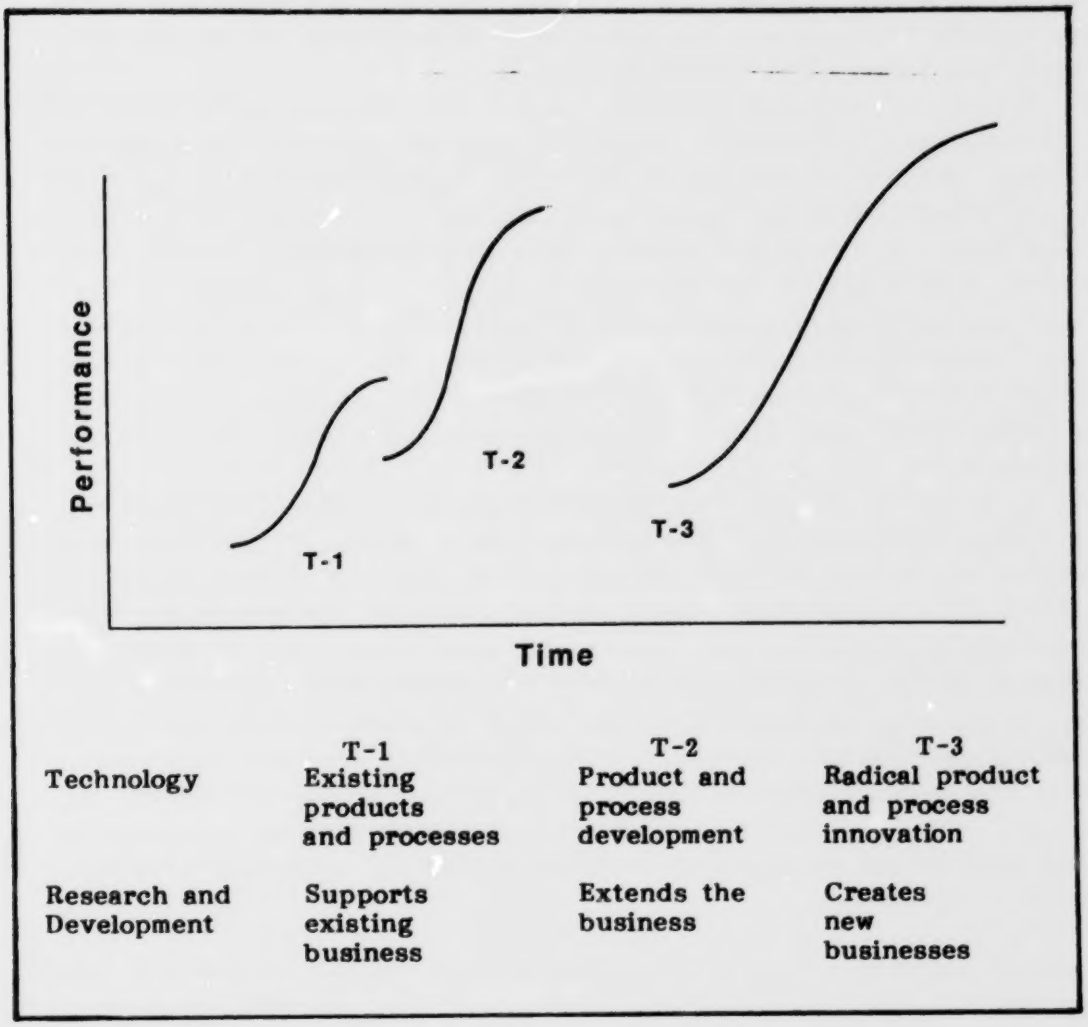
Other technologies are not specific to the mineral industry, although there may be a considerable degree of customization necessary for mineral applications. These we will refer to as "peripheral" technologies. In mining, as shown in the examples given in figure 1, the more important of these technologies include materials handling, process control, robotics, construction materials, communications, and electrical equipment. Biotechnology is rapidly emerging as another important area of interest. A similar but not identical group of peripheral technologies relevant to extractive metallurgical operations is shown in figure 2.

While mineral industry companies might be expected to be involved in developing new applications for these peripheral technologies, and customizing them to the degree necessary for effective use, they do not carry out a significant amount of direct research and development in these areas. For example, Canadian mining companies do not have the resources or expertise to carry out major development programs on communications technology. In such areas, although the industry has very specialized needs, mineral companies are dependent on equipment and process suppliers for major technological advances. The extent to which these suppliers will focus their activities on the needs of the mineral industry depends greatly on the perceived importance of the business and the receptivity of the industry to external innovation.

The mineral industry may also use a variety of other technologies particularly in administration, maintenance, and surface operations, which are not adapted or modified at all. These are generally bought in, and no innovative activity is carried out in these areas by the industry at all. These technologies will not be discussed in this study.

Incremental, Major, and Revolutionary Innovation

Technological development can also be viewed in the context of evolutionary performance "S" curves, as shown in figure 3. These curves are intended to give a crude visual representation of the way in which technologies evolve over time, make their contribution to performance, and are replaced by new technologies. Incremental changes in existing core technologies and improvements in peripheral technologies move technological performance up the T-1 curve, upgrading processes, methods and equipment in existing plants and products. Most of these improvements arise from practical experience, and may not involve any R and D effort at all. Much of the technological change in the mineral industries is of



	T-1	T-2	T-3
Technology	Existing products and processes	Product and process development	Radical product and process innovation
Research and Development	Supports existing business	Extends the business	Creates new businesses

Figure 3. Technology Evolution Curves

this nature, and progress in performance would be accomplished through a series of T-1 curves representing, for example, improvements in mechanization or in automation.

Major technological change based on existing technologies produces the T-2 type of curve. Examples of this type of development include the development of the flash smelting process for copper or non-TNT explosives, or LHD equipment. These developments can be retrofitted to existing plants or mines, but are commonly associated with expansions or new

facilities. Research and development plays a major role in the development of these technologies, but in-house technical and operations staffs have significant input into the design and demonstration of the new technology, and utimately determine its success.

Radical technological innovation, which may revolutionize an industry in the way the jet engine changed the aircraft industry, produces the T-3 type of curve. Early in its life cycle, the new technology may perform less efficiently than those in current use. However, as the technology develops, it makes existing technologies obsolete. Frequently, such new technologies will be incompatible with those already in existence, and will require new plants or products. This type of technical change frequently arises outside an existing industry, and may be brought into the industry by new entrants. The classic example for mining is the pump; more recent examples include geophysical techniques and bacterial leaching.

As noted previously, the dominant type of technological change in the mineral industries is incremental. Improvements in operating efficiency take place continuously throughout the industry without significant R&D input. Occasionally, major innovations will be introduced when plants are expanded or new plants are constructed, and a number of underground mines have recently been adapted to bulk methods. However, because of the capital intensity of the industry and the current low levels of profitability, many firms avoid new and unproven technologies unless the technical risk is small and there are significant economic advantages to be gained. Few firms in the industry possess the resources to develop radical innovations, or to refit existing operations with radically new technology.

Chapter 2. THE CANADIAN MINERAL INDUSTRY: SETTING THE POLICY SCENE

INTRODUCTION

Many of the characteristics of the Canadian mineral endowment, the industrial organization of the mineral industry, and the markets and applications for mineral products have significance for the ability of the industry to realize the technological opportunities it must pursue to retain its competitive position. For the benefit of readers who may not be familiar with the mineral industry, this chapter will look at some of the principal features that are significant in terms of their impact on innovation needs and capabilities, on the required strategies, and on who is in a position to design and to deliver the policies.

For example, among the factors adding to the complexity and the cost of R&D and innovation in the industry are the following:

- the diversity of mineral resources in the Canadian mineral endowment;
- the diversity of geological environment, deposit types, types of ore, and ground conditions found in Canada;
- the wide range of activities, from exploration through to process metallurgy, that make up mineral production activities;
- the age of existing plant and equipment in Canada;
- the diversity of end use applications and markets for mineral products.

Among the factors limiting the availability of funds for R&D and innovation are the following:

- the economic difficulties facing most mineral producers;
- the small size of the vast majority of companies in the mineral sector;
- the concentration of ownership and processing facilities in base metals, which in effect places the onus for R&D on a very few firms, for this particular but very important group of metals. On the other hand, it can be argued that this concentration of assets and cash flow in a few large firms should facilitate a concerted and cooperative approach to R&D and innovation in the base-metals industry.

Among the factors that have fragmented past R&D efforts and inhibited technology transfer activities are the following:

- the number and geographical dispersion of establishments;
- the tendency for secrecy among mining firms;
- the divided jurisdiction resulting from the federal system of government combined with provincial ownership of resources;
- the tendency for R&D projects to be conducted in-house, rather than in cooperative joint ventures or by an industry-wide research organization.

Among the factors that have focused R&D on short-term applied problems and incremental innovations rather than on more fundamental or revolutionary change are the following:

- the low level of R&D funding;
- the low level of interest in and support for mineral-related basic R&D in universities;
- the in-house nature of most industry R&D programs, aimed principally at improving existing operations or solving existing problems.

One of the most notable features of the mineral industry in Canada is its diversity. Canada produces over 60 mineral commodities, some in very large quantities and largely for export, such as coal, potash, iron ore and base metals, and some in large quantities but destined mainly for Canadian end uses in nearby markets, such as building materials. Some are produced as the sole product of a particular mine or deposit, while many of the metallic minerals are found in combination and produced as coproducts or byproducts. Some are found in only one or two locations and some minerals are found and exploited in almost every province or territory. Some are found in very large or very rich deposits (and occasionally both); other deposits are small or very low grade.

The producing companies with operating mines number under 200, and range from very small local organizations to the half-dozen or so multinationals integrated vertically into every aspect of the mineral industry, from exploration to fabrication of metal products, and in a few instances integrated horizonally in other resources and other industrial sectors. The industry also includes thousands of exploration firms and service and supply companies that do not own or operate mines. In addition, industry organizations, government departments and agencies, and universities all play important roles.

As a result of the great variety and complexity found within the industry, it is difficult to generalize about the kinds of technology it utilizes or the areas where technological advancement might make a significant improvement to its economic viability and international competitive position. This study will therefore focus on the producers of major minerals, i.e. major in terms of value of production and importance in export markets. The major minerals are identified and introduced briefly in the following section.

MINERAL TERMINOLOGY

Classification of Minerals

Minerals can be subdivided into a number of broad categories, such as metals or nonmetallics, down to the individual commodities, such as gold or copper. The following are among the major categories used in describing the industry, and some of the major minerals within each category that are produced in Canada.

METALS: Ferrous metals[a]
- iron ore
- molybdenum
- titanium
- tungsten
- silicon

Nonferrous metals

Precious metals
- gold
- silver
- platinum group

Base metals[b]
- copper
- lead
- zinc
- tin

Other nonferrous metals
- nickel
- uranium
- cadmium
- cobalt
- rhenium
- arsenic
- rare earths

INDUSTRIAL MINERALS:
- Construction materials
  - gypsum
  - cement
  - lime
  - quarry stone
  - sand and gravel (aggregate)
- Other industrial materials
  - salt
  - sodium sulphate
  - talc
  - graphite
  - mica
  - quartz
  - barite
  - nepheline syenite
  - other clay products

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[a] generally associated with steelmaking.

[b] this category is sometimes defined as including nickel and some of the metals shown above as ferrous metals.

FUELS

- coal
- uranium[c]
- oil and gas[d]

NONMETALLIC MINERALS

- asbestos
- potash
- sulphur
- plus industrial minerals, below

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[c] also classified as a metal.
[d] not covered in this study.

Mineral Products

Ore is a mixture of minerals and waste rock from which at least one of the minerals can be extracted at a profit. Ore is the direct product of mining. It is usually blasted and dug straight from the mineral deposit, and possibly reduced in size by primary crushing. It is high in bulk and low in value. Ore is usually taken directly from the mine to a mill, either at the minesite or fairly near by, for further processing. One exception is direct-shipping iron ore, which can be shipped from Canadian mines to steel mills in Canada, the United States, and overseas, although most Canadian iron ore must be beneficiated before shipping. Some coal and many industrial minerals are also shipped with minimal processing.

Concentrate is a product containing valuable minerals from which much of the waste material in the ore has been removed by physical and chemical separation processes in the mill. For example, a copper mine may have ore grading 2 percent copper which yields a concentrate containing 25 percent copper. Concentrate then goes to a smelter for further purification. Smelters require large capital outlays for their construction, and large market for their products in order to achieve the necessary economies of scale. Because Canada is a relatively small market for metals, relative to its production levels, much of its concentrate production is exported to smelters in major industrialized countries. For example, exports account for about 40 percent of copper, lead and zinc concentrate shipments, 80 percent of iron ore, 96 percent of asbestos, over 99 percent of molybdenum, but zero percent of nickel is exported as concentrate.

A smelter product is an impure metal or combination of metals from which the concentrate wastes have been removed. For example, a 25-percent copper concentrate may be transformed in the smelter, in a series of steps, into a 99-percent pure blister copper.

A refinery product is a purified metal product meeting industrial end-use specifications. For example, blister copper can be upgraded to cathodes of 99.99 percent purity. Uranium concentrate, or yellowcake, is refined into uranium dioxide for use in Canadian nuclear reactors, or uranium hexafluoride which is subsequently enriched for use in light-water reactors.

MAJOR MINERAL COMMODITIES

Introduction

The characteristics of the Canadian mineral industry are far from uniform, and broad generalizations or macro studies are therefore rarely applicable to all aspects of the industry. The issues and problems of the industry must be considered by individual commodities. This section will look at the eight leading mineral commodities produced in Canada, plus aluminum, identifying some of the special factors that offer constraints to or opportunities for technological innovation for each.

Because most Canadian base metal mines are polymetallic, it is misleading to consider metals on a stand-alone basis. For example, prices and demand for zinc have a significant impact of volumes of production of lead and silver, which are often found in the sames ores. Revenues from byproduct gold and silver have kept many base metals in the black over prolonged periods. Consequently, the polymetallic nature of deposits is considered here as well.

The eight leading commodities, as shown in table 1, represented about 60 percent of the value of production in 1984, and all except gold are dependent on export markets. Throughout this study, these eight, plus aluminum, will be singled out from time to time for more detailed comments. Of the remaining leading commodities, most are building materials which do not move great distances, and which are affected by local construction demand rather than by international market conditions. The major exceptions are sulphur, asbestos and lead, which will also be mentioned individually where appropriate.

Table 1

RANKING AND VALUE OF CANADIAN PRODUCTION OF LEADING COMMODITIES, 1984

Rank	Commodity	Value of Production ($ million)
1	coal	1,814
2	iron ore	1,471
3	zinc	1,438
4	copper	1,351
5	gold	1,228
6	nickel	1,165
7	uranium	916
8	potash	759
9	cement	667
10	sand and gravel	591
11	sulphur (elemental)	574
12	asbestos	412
13	silver	409
14	stone	334
15	salt	214
16	lead	191
17	lime	175
18	clay products	141
	other minerals	1,032
	Total value of minerals (excluding oil and gas)	14,887

Coal[1]

The Canadian coal industry has been setting new records in recent years. Production, domestic consumption, exports and imports all reached new highs in 1983, and 1984, as new producers came on stream in western Canada. The primary producing provinces are Alberta, British Columbia, Nova Scotia, New Brunswick, and Saskatchewan.

1. Based on "Coal" by J.A. Aylsworth, Canadian Mining Journal, February 1985.

The major domestic use for coal is in the utility sector, which accounts for approximately 80 percent of Canadian coal consumption. Domestic consumption of coking coal is linked to conditions in the domestic steel industry.

Canada is a net coal exporter; in 1983, 53 percent of Canadian production (tonnes) was exported. Japan is a major export market, accounting for approximately two thirds of total Canadian exports in 1983. The entry into production of new western mines with Japanese contracts is expected to increase exports by 48 percent over 1983 levels.

Although production volumes overall in Canada have increased, depressed prices have affected all producers, and shifting of purchases agreements to new producers has hurt some of the older mines.

Employment has stayed fairly steady in recent years, in spite of increases in production. The total employment in the coal mining sector was 11,000 in April 1982, fell to 9,800 in 1984, and was back up to 11,000 in April 1985.[2] Over the same period, volume of production rose from 42.8 million to 57.4 million tonnes per year.

Technological innovation in the coal mining industry has generally been transferred into Canada from other producing countries, principally the U.K., and has followed the pressures of competitive necessity, rather than "a planned and general search effort for new techniques".[3] Through 1960 to 1980, increased production relied mainly on application of existing surface mining technology, on scaling up of equipment, and improved stripping ratios. R&D efforts were initiated by its federal government over this period, focusing on optimization of open-pit design (the Pit-Slope Project) reserve/resource assessment, mining technology, health and safety, and environmental control. Federal funding supported the development and upgrading of additional government research facilities in some provinces, as well as some R&D activities among private sector supplies and consultants.

Short-term R&D needs in the coal industry include improved information on reserves and resources; increased efficiencies, for example though more automation, in open-pit operations; and, for the underground sector, the extension of known methods such as longwalling and hydraulic mining to new environments. In the long-term, attention should be directed to the development of extraction technologies for underground mining of thick, sharply dipping and multiple coal seams.

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2. EMR, "Mining Industry Employment Update" October 1985, unpublished internal document.
3. T.S. Cochrane, "Technological Innovation and Canadian Coal Mining", CIM Bulletin, May 1985, p. 58.

Iron Ore[4]

The Canadian iron ore industry has been going through a process of rationalization since the mid 1970s. The number of mines fell from the 70s peak of 17 operating at 90 percent capacity to only 8 in 1984, operating at less than 66 percent capacity. By 1986 there were only 6 mines in operation, with the majority of production coming from the Labrador Trough region, and smaller operations in Ontario. Employment fell from a peak of 16,000 to under 7,000 in 1986.

The outlook for the Canadian iron ore industry is not good. World iron ore production capacity utilization was estimated to be about 43 percent in 1983, with little prospect for an increase in demand. Furthermore, additional capacity is under construction in other countries, particularly Brazil. Brazil has high-grade ore that is easily mined and requires little beneficiation, as well as low labour costs. Australia and India are also major low-cost competitors. Canada, with lower grades and higher costs than Brazil and Australia, does have some benefits in terms of market access resulting from vertical integration with North American steel producers. However, competitive position over the longer term will depend heavily on continuing rationalization (i.e. closure of high-cost facilities), productivity improvements, attention to product quality, and marketing efforts.

Research in the industry is focusing on productivity improvements, reduction in energy costs, and development of new iron ore products. To this end, studies under way include: coal-water slurries; direct reduction; plasma technology; and self-fluxed pellets.

Polymetallic Metal Mines

Discussion of individual metals should not be allowed to disguise the fact that most Canadian metal mines are polymetallic. Of the seven major metals produced - copper, zinc, nickel, gold, silver, lead, and molybdenum - as many as five may be recovered from the same ore. The polymetallic character of Canadian ores has several important implications, both positive and negative, for producers. For example:

- it helps to smooth out the cyclical variations in individual metal prices;

4. Based in part on B.W. Boyd, "Iron Ore", Canadian Mining Journal, February 1985, pp. 64-66.

- production levels of metals are linked - e.g. increased demand for zinc can mean increased production of coproduct lead (regardless of price or demand conditions) and of byproduct silver;
- a number of base metal mines, particularly copper mines, have stayed viable over many years only because of the revenues from by-product precious metals.

Although it may be misleading to identify a mine by a single commodity, as for example a "copper mine" or a "zinc mine", the principal metal is often used as a designation. Table 2 shows the base metal mixes found in Canadian mines, using the principal metal as the means of classification. Gold and silver are also found in conjunction with base metals. Almost 80 percent of gold is produced from a gold-only concentrate, in contrast to silver, with only about 7 percent in a silver-only concentrate.

Table 2

BASE METALS PRODUCED TOGETHER FROM MINES IN CANADA, 1983

Principal Metal	Associated Base Metals	Percentage of Each Combination of Associated Metals in Concentrates
Copper	Zn & Pb	8
	Zn	27
	Ni	15
	Mo	21
	none	22
Nickel	Cu	100
Zinc	Cu & Pb	38
	Cu	29
	Pb or none	33
Lead	Cu & Zn	42
	Zn or none	58

Source: adapted from EMR, Canadian Mines: Perspective from 1984, Ottawa, 1985.

Zinc[5]

Canadian zinc production rose by more than 10 percent in 1984, to an estimated 1.185 million tonnes. In 1983 New Brunswick was the major producer, with production valued $269 million, followed closely by the Northwest Territories at $257 million. B.C. was a distant third, at $114 million, and Newfoundland, Quebec and Ontario each produced in the $40-50 million range. Saskatchewan's production was valued at $6.8 million. As noted above, Canada's zinc mines also produce copper and lead, and frequently silver as well. A number of reopenings or new projects are planned or under consideration for zinc mining, and several expansions in zinc smelting facilities are in progress.

In spite of the scattered nature of the zinc mining operations, from east to west coasts and in the Arctic, the sector is fairly integrated in terms of smelting and refining operations. Cominco's Trail facility, Kidd Creek's Timmins operations, and the Brunswick smelter are tied to their nearby deposits, while HBMS's Flin Flon facility is in part a custom smelter, and the CEZ facility at Montreal is a custom smelter affiliated with Noranda. Refined zinc production in 1983 was estimated at 617,000 tonnes. Exports were 500,000 tonnes refined and 660,790 in ores and concentrates (compared to copper, with refined production 464,000 tonnes, refined exports, 299,000 tonnes, ore and matte exports, 314,000 tonnes).

At 1984 prices, most of Canada's zinc producers were able to cover cash costs.[6] The revenues from coproduct and byproduct metals have been a definite advantage to Canadian zinc producers in the past. However, weak prices for lead, copper, and precious metals have reduced this advantage in recent years. Canada's competitive position in zinc smelting and refining is even stronger than in zinc mining, with costs estimated to be the lowest in the western world. This advantage is attributed to low electrical energy costs and modern plants.

Although zinc markets improved temporarily in late 1983 and early 1984, demand and prices continued their long-term downward trend in the second half of 1984 and in 1985. Overcapacity worldwide is expected to continue this trend at least until the 1990s.

Canada is relatively well-placed on the cost curve for international competition in zinc export markets. Future efforts must be aimed at further cost reductions, particularly in underground mining, and at aggressive marketing, including development of new applications for zinc.

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5. Based on M.J. Gauvin, "Zinc", Canadian Mining Journal, February 1985, pp. 52-54.
6. EMR, Canada's Nonferrous Metals Industry: Lead and Zinc, A Special Report, 1985.

At some future time, development of a new zinc reduction plant in eastern Canada may become practical, and several new processes presently in the development stage may be applicable if they can be commercially proven.

Copper

Copper production is even more widely spread than zinc, with 38 mines producing copper in 1983, compared to 24 for zinc. British Columbia is still the leading producer, with 286,000 tonnes in 1983. However, a number of B.C.'s copper mines have closed in recent years. The B.C. deposits are large open pit mines, with grades as low as 0.14 (Brenda) but generally in the range of 0.25 to 0.45 percent. Ontario, in second place with 197,000 tonnes and Quebec at 63,000 tonnes have higher grade underground mines (over 3 percent for Noranda's Horne Division and BP Selco's Joutel mine in Quebec), but most are in the range of 1 percent to 2.5 percent). Copper mines are usually polymetallic, with associated coproducts and byproducts. For example, the Kidd Creek mine in Ontario contains copper, lead, zinc, silver, and small amounts of gold, cadmium and other metals, and some of the B.C. mines include molybdenum.

From the west coast, much of the copper production is shipped as concentrate to Pacific Rim smelters. In the east, a high proportion is processed in Canada. However, due to declining mine production, some of the older eastern smelters, built originally to serve adjacent large mines and now operating as custom smelters, have been forced to cut back operations and/or to seek concentrates from more distant sources with higher transportation costs. Noranda's Horne smelter and the Hudson Bay smelter at Flin Flon both face environmental upgrading programs to reduce SO_2 emissions which may significantly affect their cost competitiveness.

The competitive position of Canada's copper producers has deteriorated sharply since 1981, when prices for byproduct metals such as molybdenum began to drop, eliminating a Canadian advantage. Other factors pushing Canada upward on the cost curve include the strong Canadian dollar, rising energy and labour costs, and, in some cases, cutbacks or temporary closures.[7]

World copper markets are characterized by overcapacity and weak demand and prices, with no prospects for strong recovery in the medium term. Strong competition is offered by a number of developing nations with rich deposits, low labour costs, and good management. Demand for

7. EMR, Canada's Nonferrous Metals Industry: Nickel and Copper, 1984.

copper is being eroded by substitution in many traditional applications. For example, aluminium is replacing copper in automotive radiators and high voltage cables. Plastic is replacing copper in many construction applications, and fibre-optics are being substituted in communications applications.

Canadian response to this situation will be continued rationalization through closure of high-cost production facilities, cost reductions in mining and processing, direction of exploration to small and rich deposits rather than large low-grade deposits. Research into new products is now under way, although on a relatively small scale.

Gold[8]

In Canada in 1984, gold production increased by 9.5 percent over the 1983 level, in spite of the fact that the price of gold fell to slightly above $300 U.S. per ounce, a 2-year low. This drop in price, occurring over an 18-month period, caused problems for higher-cost producers and led to some mine closures. It also caused problems for base metal producers with gold byproducts.

Gold is produced in all provinces and territories in Canada, with the exception of P.E.I. and Nova Scotia (the latter is a former producer, with an active exploration program). Quebec is the major producer, with a number of established camps, several new mines which opened in 1984 and 1985, and more under development. In Ontario, new mines have come on stream in several areas, principally the Hemlo camp, and exploration and property development continued to be active.

The future for gold prices is unpredictable at best, since it depends on many economic variables, such as the strength of the U.S. economy, interest rates, inflation rates, gold sales from the Soviet bloc, and the ability of OPEC countries to control oil prices. In spite of the fact that long-term forecasts of gold prices do not look particularly promising, production is increasing in countries such as Canada, the United States, Brazil, and Australia, due both to new discoveries and to the mining of low grade ore which has become economically viable through the use of new technologies, principally leaching.

New industrial uses for gold have emerged in recent years, in electronics and architecture, for example. However, its principle industrial application remains jewelry. In fact, jewelry demand has overtaken investment demand in recent years. Due to its high value, there is major recycling activity for this metal, and the stocks endure forever.

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8. Based on "Gold" by D. Law-West, in the Canadian Mining Journal, February 1985, p. 52.

Nickel[9]

Nickel is produced in Ontario and in Manitoba. In 1983, Canada was the world's second largest producer of nickel, with 18.7 percent of total world output, second only to the USSR. Because of high quality deposits containing many byproducts, up-to-date mining techniques, a skilled work force, and generally modern processing facilities, Canada is among the lowest cost producers of nickel, in spite of labour costs which are high relative to those of other nickel-producing countries. Furthermore, its strong competitive position is expected to continue to the 1990s, as a result of productivity improvements due to innovations in methods and equipment.

Other competitors, for example, in Australia and Botswana, will not be able to match Canada's productivity improvements because of differences in their orebodies. However, Canada's competitive position is hampered by trade restrictions such as Japanese and Brazilian tariffs which were put in place in order to protect the domestic nickel industries in these countries.

Demand for nickel is expected to grow very slowly: by 1.7 percent to 1990, then 1.6 percent to the year 2000. Prices have been weak for some years, although over the long run they are expected to increase somewhat, since little capacity expansion is expected to occur before 1990. In Canada, production is expected to increase significantly from the low levels of 1982 as unused capacity is brought back into production.

Technological advances have had some cost cutting effects in the Canadian nickel industry. Inco predicts a decrease in unit mining costs of up to 25 percent due to lower cost bulk mining methods developed in some from the Ontario government which requires all Sudbury ore to be refined of their Sudbury operations. At Inco Thompson, increased use of these techniques as well as a new open pit mine are expected to significantly lower costs.

Both the major Canadian producers, Inco and Falconbridge, are faced with SO_2 containment programs at their smelters over the next decade which will increase costs. In addition, Falconbridge faces an order-in-council requiring it to process its Canadian concentrates in Canada by 1990; at present, the concentrate is refined at its facility in Norway.

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9. Based on "Nickel" by R.G. Telewiak, Canadian Mining Journal, February 1985, and Canada's Non-Ferrous Metals Industry: Nickel & Copper, EMR, 1984.

The Nickel Development Institute, an organization of western world nickel producers, was formed in 1984 for the purpose of carrying out R&D in new applications for nickel and promotion of nickel use in major markets. Some applications with market potential include pollution abatement equipment, nickel-cadmium batteries, and various nickel-based alloys and superalloys.

Uranium[10]

As of 1984, Canada is the world's leading uranium producer, with over 20 percent of total world production. Canada is also the world's largest exporter of uranium, with South Africa and Australia following closely.

The majority of Canadian production (55 percent) comes from Saskatchewan, with the remainder originating in Ontario, with older, lower grade and higher cost mines. Exploration is still active, as uranium demand is forecast to grow at a rate of 6 percent per year to 1990. Currently, however, uranium production and expansion are constrained by large inventories, estimated at 4-5 years' supply, which can meet a large part of the expected demand growth. However, the inventory problem showed signs of easing by late 1985.

Canada has secured a significant number of new export contracts in recent years; the principal buyers are Japan, the USA and the U.K., and its leading position in exports is expected to last into the near future at least.

By the end of 1987, Canada's uranium production capacity will have increased significantly, with the completion of expansions in both Saskatchewan and Ontario. No new capacity is expected to be brought into production before the 1990s because of the continuing high inventory situation. It may well be that, until the 1990s, Canada will be producing below capacity.

Much of the pressure for technological innovation in the uranium industry will arise from health, safety and environmental requirements, as a result of more stringent standards as well as the very high grades of the newer deposits.

Potash[11]

Canada is a major player in the world potash industry. For 1983, the U.S. Bureau of Mines estimates Canadian sales at 6.2 million tonnes or

10. Based on "Uranium" by R.T. Whillans, in the Canadian Mining Journal, February 1985.
11. Based on "Potash" by G.S. Barry in the Canadian Mining Journal, February 1985.

23.2 percent of estimated total world production. Canadian potash is mined primarily in Saskatchewan, and production began in New Brunswick as well in 1983.

Saskatchewan has high quality potash, and production costs that are in general the lowest in the world, in spite of the great depth of the deposits. A major part of this cost advantage is due to the advanced technology employed in many Canadian mines. High production volumes permit the use of continuous mining systems, resulting in low unit production costs. This cost advantage is largely offset in offshore markets because of the high cost of rail transport to the port of shipping, although for U.S. markets, transportation costs are not as significant.

A large share of Saskatchewan capacity, 41.7 percent, is owned by the provincial Crown corporation, the Potash Corporation of Saskatchewan (PCS). PCS has shelved most of the plans for capacity expansion it had previously undertaken as a result of overoptimistic market projections. Among the private sector producers, only Kalium Chemicals is currently expanding capacity. In New Brunswick, because of their more favourable location close to shipping ports, producers may have a competitive advantage over those in Saskatchewan in both offshore and eastern U.S. markets. A mine in Manitoba is also under consideration, in spite of the current weak markets.

Worldwide, a major although somewhat unpredictable competitor with Canada in potash markets is the USSR. Jordan and Israel have become important competitors over the recent years. In the USA the major domestic potash production comes from high-cost mines in New Mexico, which supply a small part of the U.S. market, in competition with lower-cost Canadian potash.

Markets for potash have remained relatively depressed since 1982. Prices are currently viewed as being weak, and demand forecasts for potash have been consistently high over the years. Demand is generally expected to be fairly stable throughout 1986 and 1987, and the industry believes that demand will be large enough to absorb increased output arising from the capacity expansions presently under way. China, a major buyer in 1983, made no purchase in 1984 and its future intentions are still unknown. New capacity will probably be required by the early 1990s.

Aluminum

World aluminum production peaked in early 1981 at just under 13 million tonnes, and declined to less than 11 million tonnes in 1983. Prices fell

more than demand, from a peak of nearly $2,000 U.S. in 1980 to under $1,000 U.S. in late 1982. Price and demand both recovered somewhat in 1984, but further reductions occurred in 1985.

The aluminum industry faces a problem of chronic overcapacity in ingot capacity, coupled with declining markets due to substitution. During the 1970s, many new producers in developing nations came into production, as a result of strong growth in demand for aluminum in new applications, such as beverage cans, electrical transmission, and automobile components. Current trends suggest that the position will reverse during the next decade, as new materials substitute for aluminum in several of these important markets. For instance, Coca Cola is currently test-marketing plastic soft drink cans intended to replace aluminum in its largest single North American application.

Canada does not produce bauxite but, due to the availability of low cost hydro-electric power, is a major producer of primary aluminum, principally from Alcan's operations in Quebec and British Columbia. Canadian production of aluminum in 1984 amounted to 1.2 million tonnes, ten percent of world production. Approximately half this production, 628,000 tonnes, was exported. At this rate of output, Canadian smelters were operating at capacity, while the rest of the world industry was operating at less than 85 percent.

Existing producers in Canada are Alcan in Arvida and Kitimat and Reynolds Metals in Baie Comeau. The strong demand seen in 1981 and 1982 induced a wave of expansion programs at all these facilities, plus plans for new smelters including one to be built by Pechiney at Becancour, Quebec. These developments were predicted on continued demand growth, and Canada's relatively low cost power position. Several of the projects have now been postponed, pending a resumption of favourable market conditions.

Faced with the prospect of continuing overcapacity and substitution, large aluminum producers such as Alcoa and Alcan are actively seeking new products and new applications for existing products. New products for transportation industries and power generation are being developed. In addition, the companies are making a vigorous defence of their existing beverage can markets, particularly beer cans. Alcan has almost doubled its spending on R&D in the last five years, shifting a major proportion to the search for new products.

ECONOMIC IMPACT OF THE MINERAL INDUSTRY

Introduction

Canada has evolved since its earliest days as a nation dependent on natural resource exports for its economic well-being. First furs, then forest products, and later, agricultural goods and minerals, have all made important contributions to the country's political and economic development. The mineral sector contributed about $40 billion to Canada's gross domestic product in 1985, or just under 5 percent of GDP. The contribution of the sector rises much higher in some provinces: in Newfoundland, for example, over 14 percent of GPP is derived from minerals.

The industry makes an important contribution to Canada's balance of payments, accounting for about 20 percent of Canada's exports by value; mineral exports reached a total of $16.6 billion in 1984. The mineral sector provides about 4 percent of employment in Canada, with the proportion rising much higher in some regions. More detailed information on economic impact is given below, and in appendix tables A1-A10.

Value of Mineral Production: Canada

The value of production of crude minerals (excluding oil and gas) in Canada has grown from about $470 million in 1945 to over $15 billion in 1985 (see appendix table A1). From table 3 below, it is apparent that metallic minerals have fallen off somewhat in terms of value in recent years, while coal has made significant gains. Although much of Canada's mineral production is exported in crude or concentrate form (see appendix table A7), further processing adds considerably to the contribution of the sector, as shown in table 3 for 1980 and 1982.

Long-term trends in the value of Canadian mineral production can be determined from the data in appendix table A1. The generally steady growth rate from 1945 to 1980 is clearly arrested in 1981, particularly for metallic minerals which are the major source of strength in the industry.

Value of Mineral Production: Provinces

Ontario is the leading province in terms of value of mineral production (see table 4 and appendix table A3), with by far the strongest contribution in metallic minerals, worth over $3 billion in 1985. Alberta has no metal mines, but makes a strong showing due to its production of sulphur

Table 3

VALUE OF MINERAL PRODUCTION
($ million)

Activity	1980	1982	1984	1985
Metallic mining	9,697	6,874	8,510	8,547
Nonmetallic mining[a]	2,532	1,979	2,212	2,434
Structural materials	1,669	1,730	1,906	1,991
Coal	932	1,294	1,814	1,884
Total mining[b]	14,830	12,093	14,885	15,282
Smelting and refining	4,978	4,222	n.a.	n.a.
Primary metals[c]	10,397	9,218	n.a.	n.a.
Metals fabricating[c]	12,808	12,514	n.a.	n.a.
Total mineral sector[d]	44,074	38,733	n.a.	n.a.

Source: Statistics Canada - see also appendix tables A1 and A2.

n.a. = not available
[a] Includes peat
[b] Includes "other minerals" for 1982.
[c] Excluding oil and gas, and excluding nonmetallic mineral manufacturing.

Table 4

RANKING OF PROVINCES BY VALUE OF MINERAL PRODUCTION, 1984
($ million)

	Metals	Nonmetals	Structural Materials	Coal	Other	Total[1]
Ontario	3,314	210	724	-	170	4,419
B.C.	1,098	133	228	1,027	1	2,487
Quebec	1,147	369	375	-	153	2,043
Saskatchewan	399	507	47	115	2	1,369
Alberta	-	590	269	480	-	1,338
Newfoundland	933	32	29	-	-	994
NWT	618	-	49	-	33	701
Manitoba	472	20	88	-	10	591
New Brunswick	472	35	40	30	13	590
Nova Scotia	-	76	55	163	-	293
Yukon	57	2	2	-	-	60
PEI	-	-	1	-	-	1

Source: Canadian Mining Journal, February 1985.
[1] Some error due to rounding

(a byproduct of the gas industry) and coal. The ranking of the provinces varies slightly from year to year with changing circumstances. Yukon for example had a very low production figure in 1984, only $60 million, compared with the 1981 production value of almost $300 million, due to a number of mine closures. B.C.'s coal production has taken a major jump in recent years with the opening of the northeast coal development, which more than doubled the value of production from the 1981 level of $500 million.

The ranking of provinces takes on an entirely different appearance, however, when considering provincial dependence on mining (see appendix table A4). Newfoundland shows the greatest dependence, with over 14 percent of the gross provincial product arising in the mineral sector; New Brunswick and Saskatchewan follow with over 7 percent. In Ontario and Quebec, the sector contributes under 3 percent. The figures for the Yukon and Northwest Territories, not shown in the table, would show a dependence almost double that of Newfoundland, although this figure fell off sharply for the Yukon in 1982 due to mine closures.

Contribution to GNP

The mineral sector's contribution to Canada's gross national product (GNP) in recent years has fallen from 5 percent or better before 1981 to 4.3 percent in 1982, recovering to about 4.7 percent by 1984 (see appendix table A5). The decline in the mineral sector's contribution which began in 1980 has not been matched by the other resource sectors (agriculture, fishing and trapping, forestry, and petroleum); in fact, agriculture and petroleum have shown gains over the same period.

Comparing indices of GDP (see appendix table A6), using 1971 as a base year, metal mines stood at only 99.3 in 1983, and reached 109 in 1984, while manufacturing stood at 129 and 140 respectively, and the overall GDP index climbed from 143 to 149.

Exports

About 75 percent of Canada's mineral production is exported, either in crude form (ores and concentrates) or as fabricated products. Mineral products represent about 20 percent of Canada's total exports by value, a significant contribution to Canada's trade balance. Major markets for Canadian minerals in 1983 were as follows: United States (50.2 percent), Japan (13 percent), European Economic Community excluding U.K. (10.6 percent) and the United Kindgom (6 percent).

Despite the high level of mineral exports, Canada is by no means self-sufficient in minerals and metals. Value of imports of minerals and metals amounts to about 40 percent of the value of mineral and metal exports each year.

The value of mineral exports in 1983 was almost $15 billion, of which more than half represented material in fabricated form (see appendix table A7). In 1984, the total figure climbed to $16.6 billion. The mineral sector is the leading resource sector in terms of value of exports, followed closely by forestry, as shown in table 5.

Table 5

VALUE OF CRUDE AND FABRICATED EXPORTS IN THE PRIMARY RESOURCE SECTION, 1980 and 1983
($ million)

Resource Sector	1980	1983
Mineral Sector		
Ferrous	3,701	3,065
Nonferrous	9,140	7,471
Nonmetals	2,718	2,528
Coal	1,399	1,876
Total[1]	15,603	13,450
Agriculture	8,186	8,991
Fishing/Trapping	1,265	1,566
Forestry	12,731	13,136
Petroleum	9,207	10,234

Source: Appendix tables A7 and A8.

[1] Total includes additional categories not shown in this table.

Employment

Employment figures in any sector must be used with caution, and this is especially true for sectors such as mining with strong seasonal and cyclical variations. In many cases, seemingly similar published tables of employment figures on a yearly basis will appear to be in disagreement, because each may use different point-in-time figures, or annual averages, or averages for different selected months.

According to Statistics Canada data, direct employment in the mineral sector (including fabricating) accounts for under 4 percent of total Canadian employment (see Appendix table A9), with about 81,700 employees in 1984, down from 95,600 in 1980. Mining itself accounts for less than one percent of total employment in Canada. The EMR Census of Mines data in table 6 show that all sectors of the industry except coal experienced declines in employment in 1982 and 1983. These averaged yearly figures, however, hide the fact that in mid-1982 close to half the Canadian mining sector was shut down, for periods ranging from a few weeks to several months.

Table 6

EMPLOYMENT IN THE MINERAL INDUSTRY[a]
(thousand)

	1980	1981	1982	1983	1984	1985
Metal mines	66	69	62	55	58	48.2
Nonmetal mines	17	16	14	13	14	12.2
Structural materials	5	4	3	3	3	n.a.
Coal	11	11	13	12	14	11.1
Total mining	99	101	92	83	90	n.a.
Smelting and refining	36	38	33	32	34	n.a.

Source: EMR Annual Census of Mines; cited in EMR Canada/Energy and Mines Manitoba, New Financial Mechanisms for Addressing Mining Community Problems, September 1985, p. 4, except 1985.

[a] Yearly averages to 1983; after 1983, averages for month of August.

Employment levels in mining are more variable than for the Canadian economy as whole, as shown in table 7.

Table 7

CANADA[1]: UNEMPLOYMENT RATES

	November 1981	November 1982	November 1983	November 1984	November 1985
Mining & Quarrying[2]	10.2	25.9	15.2	8.8	8.2
All occupations	7.9	12.2	10.7	10.9	9.8

Source: Statistics Canada, The Labour Force, 71-001.

[1] Excludes Yukon and NWT.
[2] Includes oil wells, and so understates the level of layoffs in mining.

Wages in the mineral sector are relatively high and in recent years have overtaken wages in construction (see appendix table A10). In August 1984, weekly wages averaged $625 in metal mining, and even higher for coal and smelting and refining. By contrast, wages in construction were $494; in manufacturing $463; and for all industries were $403.

INTERNATIONAL COMPETITIVE POSITION

Introduction

If the mineral sector is such a large and active sector, why are special policies and strategies needed now to promote innovation? For many years Canada has been one of the world's leading nations in terms of both mineral production and mineral exports. Access to export markets has permitted development of scale economies in mining (deposit size and grades permitting) as well as technological expertise that has kept productivity high and production costs towards the low end of the cost curve. However, in recent years Canada's position has been eroded, as a result of new entrants to mineral production, particularly in the Third World, and overcapacity in production facilities worldwide. The first factor has increased supply in the face of fairly static demand, leading to weakened prices and reduced Canadian sales; overcapacity has taken away some of the economies of scale and increased the unit costs for those Canadian producers forced to operate below full capacity.

In 1981, EMR summarized the major factors expected to affect the competitive position of the Canadian mineral industry through the 1980s in its publication, Mineral Policy: A Discussion Paper. Noranda's response to an early draft of the paper gave an even more negative reading than that predicted by EMR, as shown in table 8. Subsequent events have shown that both sets of predictions were optimistic, particularly with respect to exchange rates outside of the United States, the contribution of byproduct and coproduct metals (type of ore), and energy costs. Recent discussions of tax reform principles suggest that the taxation environment for the industry may deteriorate as well, and trade barriers are a growing concern.

Canada has the capacity to produce minerals far in excess of its own requirements, and a high level of exports must continue if the industry is remain economically sound. In order to maintain its international competitive position, the Canadian industry must meet a number of requirements:

Table 8

IMPACT OF MAJOR FACTORS AFFECTING THE COMPETITIVE POSITION OF THE CANADIAN MINERAL INDUSTRY IN THE 1980s

Factors	EMR	Noranda
Ore grade	Slightly negative	Slightly negative
Type of ore	Strongly positive	Positive
Location	Moderately negative	Moderately negative
Capital costs	Slightly negative	Slightly negative
Labour costs	Strongly negative	Strongly negative
Energy costs	Strongly positive	Positive
Exchange rates	Strongly positive (conditional)	Strongly positive (conditional)
Taxation[a]	No change anticipated	Moderately negative
Technology	Strongly positive	Strongly positive
Environment	Slightly negative	Strongly negative
Tariffs and trade barriers	No change anticipated	Slightly negative

Source: Noranda Mines Ltd., "Comments on Mineral Policy Review", unpublished, July 1981.

- it must have reserves to maintain steady or increasing levels of production;
- it must keep its position towards the low end of the cost curve, through productivity improvements and a continuing supply of high quality mineral deposits;
- it must maintain or increase its access to export markets.

Reserves are a function of Canada's mineral endowment, and table 9 and 10 give figures on ranking in terms of mineral production and reserves. The second requirement, low costs, is a function of ore grades and characteristics, good management practices, and of technological innovation which is the focus of this study. The third depends to a large extent on government trade policies, in Canada, in other producing countries, and in consuming countries.

Table 9

CANADA'S RANKING AS A WORLD MINERAL PRODUCER, SELECTED COMMODITIES, SELECTED YEARS

Mineral	Ranking		
	1975	1982	1984
Nickel	1	2	2
Zinc	1	1	1
Asbestos	2	2	2
Silver	2	4	5
Potash	2	2	3
Titanium	2	2	2
Uranium	2	2	1
Molybdenum	2	3	4
Gypsum	3	3	2
Elemental sulphur	3	2	1
Platinum group metals	3	3	3
Gold	3	3	3
Copper	4	4	4
Lead	4	4	4
Aluminum (metal)	4	3	3
Cadmium	4	4	4
Iron Ore	7	5	6

Source: EMR, Canadian Minerals Yearbook, 1976 and 1983-84, table 8, and EMR, Canadian Mineral Industry Monthly Report, February 1986.

Table 8 above suggests that Canada has relatively few comparative advantages in the mineral sector. One exception may be productivity. A study published by the Economic Council of Canada in 1979[12] found that levels of output per person in Canadian mining were about 60 percent higher than in the United States, one of Canada's major free market competitors, in 1970. The study covered 22 major commodities which accounted for more than 90 percent of output in both countries. It seems likely that these productivity indices have dropped in the Canadian mining industry somewhat since that study was made. Unfortunately, reliable data

12. D.J. Daly, Canada's Comparative Advantage, (Ottawa: Economic Council of Canada, 1979).

Table 10

CANADA'S RANKING IN KNOWN WORLD RESERVES OF SELECTED MINERAL COMMODITIES, 1981 AND 1984 ESTIMATES

	1981		1984
	Rank	Percent share	Rank
Asbestos	1	35.6	2
Cadmium	1	17.6	2
Cesium	1	75.0	1
Copper	5	6.3	5
Gold	3	2.5	4
Gypsum	2	10.3	4
Illmenite (Titanium)	1	25.2	1
Iron Ore	4	8.5	4
Lead	4	13.3	2
Molybdenum	4	6.6	4
Nickel	2	14.4	2
Platinum group	4	0.8	4
Potash	1	68.7	1
Silver	2	19.0	3
Sulphur (elemental)	1	11.0	3
Tantalum	4	8.3	5
Tungsten	2	14.8	-
Uranium	-	-	1
Zinc	1	26.8	1

Source: 1981, P.J. Cargata, National Resources and International Bargaining, (Kingston: Centre for Resource Studies, 1984), App. III; 1984, U.S. Bureau of Mines, Mineral Facts and Problems, 1985 edition.

and analyses are not available for the industry as a whole.[13] What is clear, however, is that a comparative advantage in productivity depends heavily on technological innovation, which may therefore be Canada's major key to a strong competitive position in minerals.

Another area of limited comparative advantage for Canada is quantity and quality of mineral resources. Although other countries may have

13. See M.J. Wojciechowski, ed., Mining Productivity, Proceedings No. 16, (Kingston: Centre for Resource Studies, 1985).

higher grades and larger deposits of some minerals, table 9 above indicates that Canada does have an advantage in terms of quantity of reserves of many minerals. Furthermore, the value of economic deposits being discovered per dollar of exploration expenditure has remained relatively constant in Canada since 1945, according to findings by D.A. Cranstone of EMR,[14] and by B.W. Mackenzie.[15] Mackenzie's study also demonstrates that quality of Canadian ore reserves is not declining, in large part due to advances in geological concepts and exploration technology that have more than offset the expected effects of depletion. (Depletion suggests that, all other things being equal, the best, most accessible, and biggest deposits will be found and exploited first.) Similar findings have been reported by Martin and Jen, who reported that average ore grades over the past 50 years in Canada have improved for some commodities and shown no sign of decline for others.[16] On the other hand, it should be noted that higher grade deposits are being found in other areas of the world, and Canada will require continued improvements in exploration technology to locate competitive deposits in Canada.

It is worth noting that comparative advantage, a concept that has not been analyzed quantitively for the Canadian mineral industry, should be a determinant of a host of government policies in addition to innovation, including policies for tariffs, taxation, subsidies, regional development, and other economic issues.

ORGANIZATION OF THE MINERAL INDUSTRY

Mining Companies

In considering the Canadian mineral industry, what comes to mind first is the small group of producing mining companies that are large, well known, and publicly owned. In addition, however, there are a number of other active players in the industry which also bear consideration. These include:

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14. D.A. Cranstone, "Canadian Mineral Discovery Experience Since World War II" paper presented at International Institute for Applied System Analysis, Laxenburg, Austria, December 1983.
15. B.W. Mackenzie, Mining Productivity, Proceedings No. 16, (Kingston: Centre for Resource Studies, 1985).
16. H.L. Martin and L.S. Jen, "Are Ore Grades Declining: the Canadian Experience, 1939-89", paper presented at International Institute for Applied Systems Analysis, Laxenburg, Austria, December 1983.

- junior mining companies;
- contracting and consulting firms in exploration, mine develoopment, and operations and other mining services;
- mining equipment suppliers;
- organizations and associations serving the industry.

The core of the industry consists of a handful of mining groups or companies which account for most of Canada's mineral production. These companies, some of them multinationals, are vertically integrated into activities that can include everything from exploration to new materials. Some have diversified into other resources and other industrial sectors. Then there is the much larger group of smaller companies, making up the total of about 200 producers that operated Canada's 280 producing mines in 1984 (see appendix table 11).

Ontario had the largest number of producing mines in 1984, with 52, followed closely by Quebec with 48. By commodity, coal mines were the largest group, at 45 mines. Twenty-one of these are in Alberta, where most of the coal is used, generally right at the minesite, for electrical generation within the province. Gold production was spread across 5 provinces, with 40 mines, and copper mines were equally widespread. Nickel and uranium were more limited in terms of geographic dispersion, each with production in only 2 provinces, and 14 and 7 mines respectively.

Customers for the products of the industry are world-wide. Products are sold in crude form such as ores and concentrates, as refined metal, and in fabricated forms. With minor exceptions, these products are perceived to be commodities, and little product differentiation is possible, so that competition is largely (if decreasingly) on the basis of price. Under these conditions, the state of the market is determined by the relative power of buyers and sellers. When there is over-supply, as is the case for many of Canada's mineral products at this time, customers can dictate contract terms.

The producers also have backward economic linkages to a variety of manufacturing, service, and supply companies that are partially or totally dependent on the industry for their prosperity. Some of these firms supply specialized services, such as exploration, construction, or mine engineering consulting. Others may provide more general services, such as machine shops, foundries, and distribution, but are located in the many communities throughout Canada which are greatly dependent on the mining industry for their survival.

Table 11 shows the number of corporations in various sectors of the mineral industry, along with aggregate financial information for 1982. On

Table 11

CORPORATIONS AND AGGREGATE FINANCIAL STATISTICS IN THE CANADIAN MINERAL SECTOR, 1982

	No. of Corporations	Assets ($ million)	Sales ($ million)	Profits ($ million)
Mining				
Metal mines	176	25,111	8,153	-348
Mineral fuels[a]	1,410	62,740	24,728	6,496
Other mining[b]	4,741	11,862	4,882	96
Total mining	6,327	99,713	37,763	6,245
Mineral Manufacturing				
Primary metal products	395	14,099	10,615	-239
Nonmetallic mineral products	1,537	7,487	5,212	244
Petroleum & coal products	78	30,639	28,274	1,639
Total mineral manufacturing	2,010	52,225	44,101	1,644

Source: Energy, Mines and Resources, Canadian Mineral Industry Monthly Report, August 1985, Tables 12 and 13.

[a] includes petroleum and natural gas as well as coal. There are about 17 coal producers in Canada.
[b] includes junior mining and mining services.

average, metal mining firms are the largest in terms of total assets (excluding petroleum). "Other mining" includes a great many small firms such as junior mining companies, consultants, and contractors. In the description that follows, major attention will be paid to mining companies, i.e. companies that mine deposits and produce minerals in crude form such as concentrate. A subset of these companies also is engaged in smelting and in refining.

Concentration of Ownership

Concentration of ownership (measured in terms of share of total production) among the owners of the 280 producing mines varies widely, according to the minerals produced. A major determinant of concentration of

ownership has been characteristics of the deposits, chiefly their size and richness. Least concentrated is the building materials sector, with many low-value, high-bulk deposits scattered across the country and generally serving local markets. Ownership in lode gold mining is also fairly widespread, since the deposits tend to be fairly small, with relatively small capital requirements.

In potash, uranium and asbestos, a considerable degree of concentration has evolved because each is produced largely in one province (Saskatchewan for potash and uranium; Quebec for asbestos) where the provincial governments have deliberately moved to acquire a strong ownership or control position. The federal government, through Eldorado Nuclear, has uranium properties in both Ontario and Saskatchewan. Not surprisingly, it is in these three commodities where the greatest Canadian producer cooperation in R&D has been found.

The base metals sector has tended to have a high degree of concentration of ownership, particularly for nickel and lead/zinc. This is in part due to the existence of a few very large and rich deposits, such as the Sullivan Mine, Cominco's lead/zinc/silver mine which has been in production since 1908; Inco's Sudbury nickel holdings; and the more recent Kidd Creek lead/zinc deposit, which has also created an industry leader. Another factor increasing concentration of ownership in these metals is the size of the capital investment required to develop these very large deposits and process the ore. In 1983, for nonferrous metals, there were 130 mines and 88 concentrators or mills managed by 68 companies. Of the 130 mines (which ranged in capacity from 40,000 to 29 million tonnes of ore per year), the 10 largest produced more than half the total tonnage.[17] Concentration has become even greater with the recent takeovers of Kidd Creek (by Falconbridge) and Cominco (by Teck).

In copper, ownership has been somewhat more widespread, largely due to the existence of a number of relatively small and high-grade copper mines in Quebec. British Columbia copper mines on the other hand are much larger porphyry deposits, with fairly low grades and requiring large investments for development.

The base metal mining firms are also major producers of precious metals, chiefly as byproducts of their base metal operations. Recently, a number of base metal firms have expanded into lode gold mining as well, to protect themselves against weaknesses in base metal markets and prices.

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17. EMR, Canadian Mines: Perspective from 1984, Ottawa, 1985.

Ownership of both iron ore and asbestos is highly concentrated. In iron ore, with 9 operations and 8 companies in 1983, the three largest mines produced over 75 percent of the contained iron, and 1 company produced over 40 percent. For asbestos, the 2 largest mining and concentrating operations produced almost half of the total asbestos fibre.

Size of Mining Firms

Asset size in Canadian companies is determined in part by the size of deposit being mined and by the scale of the resulting operation. Increasing concentration through horizontal integration in mining (i.e., ownership of a number of producing mines) is another factor in determining asset size. Generally, underground mining firms tend to be smaller in terms of asset size than open-pit firms, although the three mentioned above, (Cominco, Inco, and Kidd Creek) have been exceptions to this rule because of exceptionally large deposits. Table 12 shows asset-size classes for several categories of mineral producers.

Table 12

ASSET SIZE OF CANADIAN MINING FIRMS, 1976 and 1986
(number of corporations)

Industry Sector	Less than $1 million		$1-$10 million		$10-$100 million		Over $100 million		Total	
	1976	1986	1976	1986	1976	1986	1976	1986	1976	1986
Gold	33	1	7	7	14	16	0	2	54	24
Iron ore	-	-	7	-	4	-	4	4	15	4
Other metals[a]	48	-	27	-	35	15	19	17	129	32
Nonmetals[b]	73	-	21	2	13	7	6	15	113	24

Source: 1976, C.H. Pye, Profitability in the Canadian Mining Industry, (Kingston: Centre for Resource Studies, 1981), p. 102; 1986, Canadian Mines Handbook, 1986/87, and Financial Post, Survey of Mines and Energy, 1986.

[a] Includes base metal production.
[b] Estimated for 1986.

Table 13 shows the number of corporations by asset-size class over the period 1979-83 for the metal mining industry as a whole. Table 14 demonstrates forcefully that "other mining", which includes junior mining and mining services, includes a very large group of small firms. Only the largest half-dozen or so firms in the mineral industry, all of which have assets over $1 billion and are vertically integrated producers (see below), have major R&D programs, as will be shown in chapter 3. The rest of the industry has to rely chiefly on purchase and transfer of new technology from outside sources in order to realize major innovation opportunities.

Table 13

NUMBER OF CORPORATIONS BY ASSET SIZE, METAL MINING INDUSTRY

	Asset Size Class ($ millions)			
	under 10	10-24.99	25 and over	Total Number of Firms
1979	53	16	55	124
1980	65	16	57	138
1981	83	22	62	167
1982	98	21	55	176
1983	86	18	55	159

Source: Statistics Canada, 61-210.

Table 14

NUMBER OF CORPORATIONS BY ASSET SIZE, OTHER MINING

	Asset Size Class ($ millions)			
	under 10	10-24.99	25 and over	Total Number of Firms
1977	2,866[a]	65[b]		2,931
1978	2,984[c]	77[d]		3,061
1979	3,530	49	58	3,637
1980	3,864	63	62	3,989
1981	4,579	66	74	4,719
1982	4,738	70	73	4,881
1983	4,748	71	67	4,886

Source: Statistics Canada, 61-210.

[a] in 1977, 773 corporations had assets of less than $5 million, while 57 had assets between 5 and 10 million.

[b] $10 million and over.

[c] in 1978, 622 corporations had assets of less than $5 million, while 47 had assets between 5 and 10 million.

[d] $10 million and over.

Vertical Integration

Vertical integration refers to the control by one company over separate units that are engaged in successive stages of production or distribution. As in the case of horizontal integration, the separate establishments may be divisions within a single company or may be separately incorporated companies in which a parent has a majority or minority interest. In the context of mineral production, the successive stages which may be integrated are exploration; development; mining and milling; smelting; refining; further fabrication; and possibly marketing.

In Canada there are 7 major base metal mining companies which are vertically integrated: Inco, Noranda, Brunswick Mining and Smelting, Falconbridge, Hudson Bay Mining and Smelting, Alcan, and Cominco. These corporations tend to have a number of producing mines supplying their further processing operations. All of them are world-scale operations. For example, Inco and Falconbridge are the first and second ranked nickel producers in the world. Noranda and Cominco Ltd. rank first and second in the production of zinc. Alcan is the world's largest aluminum producer, although none of its mines are in Canada. All these firms possess mineral reserves which have the potential to keep them in the forefront of world mineral production well into the 21st century, although not necessarily close to their processing facilities.

Smelters must be sufficiently large to achieve the economies of scale necessary for successful operation in the fiercely competitive international market for smelting services and product. This is particularly true at present, because of the large degree of smelter overcapacity world-wide. The requirement for large capital investment, as well as for a large and steady flow of concentrate, has led to the predominance of large mining companies in smelting. There are a number of advantages to be derived from combining ownership of a large deposit with ownership of a nearby smelter. The technology used in the smelting process can be shaped specifically for the ore composition of the mine, assuring optimum recovery of metals from the ore. The most efficient size of smelting operation can be built in conjunction with the long-range plan for ore extraction. The smelter has an assured supply of feed, and the mine has assured access to the smelter.

Canadian smelters treat only a portion of Canadian concentrates; the majority of concentrate is exported to smelters outside the country. See table 39 for information on proportion of concentrates exported, for selected metals. Appendix table A12 shows the major smelters and refineries operating in Canada. Note that only in precious metals and aluminum are nonproducers (i.e. companies without operating mines in Canada) involved in further processing activities.

Refineries perform the last stage in the production of a pure metal bar. The feed comes from the smelter to the refinery, where virtually all remaining impurities are removed and the metals are separated. The refining process generally requires large amounts of electrical energy. Unlike smelters, proximity to a major mine is not an important factor in determining refinery location. The availability of low-cost electrical power is one determinant. Easy access to feed may in fact locate a refinery near a smelter; or, it may be built centrally, serving a variety of sources. Particular processes such as that used by Sherritt Gordon at their nickel refinery at Fort Saskatchewan in Alberta may have some special requirement, such as the availability of natural gas, which determines location.

Although Canada is not a producer of bauxite, from which aluminum is produced, its low-cost hydroelectric power supplies have made it one of the world's leading primary aluminum producers. Alcan, the world's leading producer, maintains large bauxite reduction plants at Kitimat in British Columbia and Arvida in Quebec and plans a second in Quebec. Reynolds Aluminum has a reduction facility in Quebec, and Pechiney of France plans to build a plant in Quebec as well.

Vertical integration is of course very pronounced in the iron ore industry as well, where all Canadian producers are tied directly to steel producers in the United States and Canada.

Foreign Control in the Mining Sector

Foreign control of nonfuel mineral industry assets has fallen significantly since 1969, as shown in table 15. The 1981 figure, at 30 percent, is much lower than that for petroleum, which was 60 percent. The core of the industry, metal mining, shows the highest percent of Canadian control, according to the EMR figures in table 16. The conventional wisdom has been that foreign ownership reduces the level of R&D in Canadian firms. However, evidence in chapter 3 suggests that, if anything, the reverse has been true for the Canadian mineral sector, at least in the past.

Junior Mining

Firms engaged in junior mining are involved exclusively in exploration, holding or trading of promising mineral properties, or, in some cases, in mine development. Once their properties come into production, they

Table 15

FOREIGN CONTROL FOR NONFUEL MINING SECTOR (ASSETS)*

Year	Foreign Control (percent of sector)
1969	60.2
1970	62.3
1971	62.3
1972	48.2
1973	47.4
1974	46.7
1975	46.7
1976	44.4
1977	42.1
1978	39.3
1979	38.1
1980	33.9
1981	30.1
1982	30.4
1983	28.0

Source: 1969-81, Statistics Canada (CALURA); 1982-83, Statistics Canada 61-210.
Note: 1969-81 excludes coal and iron and steel mills, includes uranium; 1982-83 is for metal mining only.

Table 16

FOREIGN CONTROL OF FIRMS IN THE MINING INDUSTRY[a], 1976 and 1982
(percent)

	Corporations		Assets		Sales		Profits	
	1976	1982	1976	1982	1976	1982	1976	1982
Metal mines	23.2	22.7	40.9	23.1	45.3	30.3	25.5	61.4
Mineral fuels	24.3	14.0	67.3	38.3	83.0	58.8	80.9	69.5
Other mining (including mining services)	6.9	4.7	55.4	34.5	54.5	35.6	80.6	221.0[b]
Total mining	12.0	7.3	54.9	34.1	66.4	49.6	67.8	72.3

Source: Canadian Minerals Yearbook, 1978 and Canadian Mineral Industry Monthly Report, August 1985.

[a] A foreign corporation is defined as having 50% and over nonresident ownership.

[b] Profits were $96 million, distributed as follows:
Canadian corporations: -$99 million;
Foreign corporations: +$213 million;
unclassified: -$17 million.
In 1983, however, the corresponding figures were Canadian $320 million, foreign owned -$75 million.

cease, by definition, to be juniors. The distinction is based almost entirely on the presence or absence of income from mineral production. There were under 200 mining companies in Canada in 1984; since the Canadian Mines Handbook lists well over 2,000 companies, it is clear that juniors outnumber producers by about ten to one. Juniors are also, as confirmed in tables 11 and 14, much smaller in terms of asset size.

Because juniors are small and in most cases have no income, they are as a rule unable to conduct any R&D and hesitant to try out unproven technology. However, Canadian exploration equipment companies have led the world in many areas of R&D and innovation, and contributed significantly to the excellent overall performance of Canada's junior companies.

Contractors and Consulting Firms

Like junior mining firms, these companies are numerous, relatively small, and not owners of producing mines. They provide services to all aspects of the mineral production cycle: exploration; feasibility and design studies; mine development; operation or advice for mining, processing, smelting, and refining facilities; and studies in product markets and marketing. Their services may involve hands-on contract work such as exploration field programs, mine construction or operation, or construction of processing facilities; or, it may take the form of reports in areas such as geological potential, analysis of geological data, feasibility studies in mining or processing, operations and management, environmental and health and safety, productivity, and market access or market potential.

Many consulting and contracting firms specialize in mining activities exclusively, or in one aspect of mining such as exploration or marketing, while others, particularly those in the construction end, deal with a wide range of sectors comprising resource and manufacturing industries.

These firms are an important source of new technology for the industry. Unfortunately, they are rarely if ever in a position to conduct R&D, and severely limited in their ability to try out new but unproven technology because of the tight budgets and schedules under which they operate. They do, however, introduce and adapt proven technology from other countries and other sectors. In some cases they also undertake technology development and demonstration assignments for larger operating firms, equipment suppliers, or government agencies.

Equipment Suppliers

Mining and Process Equipment

Canada does not have a strong domestic mining equipment sector. The mining industry purchases a wide variety of equipment, totalling over $2 billion in 1985, as shown in table 17. These equipment purchases are made from a broad cross-section of both general and mining-specific equipment suppliers. Much of the machinery used in mining is of a general purpose nature, and is also employed in other industries such as construction. The Mineral Industry Purchasing handbook lists over 1,000 suppliers of mining equipment; for most of these firms, mining equipment is only a fraction of their total business.

Table 17

MINING EQUIPMENT RELATED EXPENDITURES, SELECTED YEARS, 1965-85
($ million)

Year	Capital Expenditures (Equipment)	Maintenance Expenditures (Equipment)	Equipment Expenditures (Total)
1965	116.9	153.9	270.8
1967	216.7	173.6	390.3
1969	199.7	154.6	354.3
1971	345.4	348.0	693.4
1973	321.0	434.9	755.9
1975	410.8	570.3	981.1
1977	649.9	776.2	1,426.1
1979	855.0	964.0	1,449.0
1981	994.0	1,348.0	2,342.0
1982	982.0	1,214.0	2,196.0
1983	828.0	1,268.0	2,096.0
1984	940.0	1,403.0	2,188.0
1985	781.0	1,326.0	2,107.0

Source: Statistics Canada, 61-206.

In 1982 the federal Department of Industry Trade and Commerce published A Profile of the Mining Machinery and Equipment Sector in Canada, which described the sector as comprising about 120 firms, largely in Ontario and Quebec, employing 6,000 people directly in the production of mining equipment. Annual shipments were about $342 million, of which about 60 percent was exported, mainly to the United States. Growth in

the sector was about 12.2 percent between 1965 and 1985, slightly ahead of both the machinery industry as a whole and total manufacturing (both 11 percent). The sector was then dominated by about 12 large foreign-owned firms whose integrated operations were not restricted to mining equipment. The sector's technical capability was described as good in the ITC study, but based largely on imported technology.

The larger Canadian equipment manufacturers that are subsidiaries of foreign corporations include Joy Manufacturing, Atlas Copco, Ingersoll Rand, Caterpillar Tractor, and Jarvis Clarke (originally Canadian-owned and still the largest domestic manufacturer of underground mining equipment). Most of these firms import a substantial proportion of their sales from foreign plants, mainly in the United States.

The foreign domination is reflected in the degree of import penetration in Canada by foreign mining equipment manufacturers. In their 1982 study, ITC reported that imports of mining machinery in 1980 captured 73 percent of the Canadian market share, up from 52 percent in 1965. In appendix table B2, a representative sampling of relevant equipment categories from Statistics Canada import data reflects an increasing trend in imports from 1976 through 1980, although a levelling off is seen between 1980 and 1984.

More precise figures on Canadian capabilities were provided in an earlier (1979) study, produced jointly by the Mining Association of Canada and Energy, Mines and Resources, on the Canadian content of equipment currently in use in mining operations in Canada. The findings of this study, detailed by type of equipment, are provided in appendix table B1. Canada's domestic capability was found to be deficient (defined as less than 50 percent of domestic requirements) in 46 out of 118 equipment categories studied.

Most of the Canadian-owned manufacturers are small, with sales of less than $10 million annually. They face considerable disadvantages compared to larger firms in terms of scale economies, distribution facilities, and access to technology. More importantly, since mining firms tend to be conservative purchasers of equipment, these small firms are at an additional disadvantage because they are generally perceived to be less stable, and unable to match the service offered by the larger firms.

To offset this disadvantage, some Canadian equipment suppliers are also distributors of foreign equipment. For example, Blackwood Hodge Limited derives approximately 80 percent of its revenues from the distribution of imported equipment and the remainder from its own manufacturing. Other manufacturers have attempted to find niches in the marketplace which may not be of interest to larger firms, and in which they can enjoy a relative technological advantage. Jarvis Clarke was the most suc-

cessful, using this approach to capture a major share of the underground mobile equipment market in Canada before its takeover and subsequent resale.

Exploration Equipment

The Canadian mining exploration equipment industry has been particularly successful, and rates special mention. Unlike the mining equipment sector, there is significant Canadian ownership of the exploration instrument manufacturing companies. In mid-1985 the sector consisted of about 15 companies which develop, manufacture and sell geophysical and geochemical instruments. Some of these manufacturers also provide contract services such as airborne or ground surveys. These 15 firms carry out most of the R&D and technological innovation for the exploration industry in Canada, and are world leaders as well. The equipment industry grew during the 1960s through exports, principally to the third world. Its growth was financed largely by contracts and support from foreign, principally U.S., mining firms.[18]

Exports still constitute the major market for Canadian firms; for example, for Scintrex, a manufacturer of geophysical equipment, the export market has accounted for more than 70 percent of its earth science sales for more than a decade. Unfortunately, the economic problems in the mineral sector world-wide, as well as debt and foreign exchange problems, have severely reduced this market in recent years.

Future Canadian private sector R&D efforts in geophysical and geochemical instrumentation will be constrained by three factors:

- reduced sales and cash flow in the sector due to a decline in exploration activities world-wide;
- escalating cost of equipment development, as the instrumentation becomes increasingly sophisticated;
- increased subsidization of this sector by governments in several other countries.

Industry Organizations and Associations

The mineral industry is served by a very large number and wide variety of organizations that can be classified in many different ways. For example:

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18. See, for example, H. Seigel, "Research in Mining Geophysics in Canada", Research and Development Bulletin, Supply and Services Canada, September 1982.

- by purpose (e.g. scientific, lobbying, etc.)
- by geographic base (e.g. provincial, Canadian, international etc.)
- by mineral activity (e.g. geosciences, mining, processing, marketing, etc.)
- by kind of membership (e.g. individual, corporate, government agency, etc.)

For the purpose of this study, it seems most useful to categorize primarily by purpose, with some reference to the other characteristics where they are relevant. Because many organizations pursue a number of purposes, assignment to any one classification is not clear-cut, but rather based on the principal orientation of the organization.

The classifications selected are:

- scientific;
- professional;
- promotional (lobbying);
- professional and lobbying;
- research and development;
- marketing;
- liaison.

It might be expected that, in investigating technology issues, scientific and R&D would be the only categories of interest. This, however, is not the case, as virtually all the organizations seem to play a significant role in the area of communications and technology transfer. For example, all of the professional organizations hold meetings at which technical papers are presented. Some also provide professional development courses, such training in computer applications for design or operations, or in new equipment or operating methods. Most of the promotion or lobbying groups are involved in information gathering and dissemination to their member companies, and many have R&D or technology committees. International groups interested in commodity marketing also hold technical meetings, covering topics such as exploration, mining, recycling, and chemical and metallurgical applications, as well as potential markets and new applications.

The list that follows is by no means exhaustive, but illustrates the variety of organizations.

Scientific and Professional: members are either individuals or companies and other organizations, and the primary purposes are: the exchange of results of scientific research and practical experience, through meetings

and publications; and professional development and support. Financial support is often received from governments.

e.g. Geological Association of Canada
Canadian Exploration Geophysical Society
Canadian Geophysical Union
Canadian Geoscience Council
Mineralogical Association of Canada
Canadian Institute of Mining and Metallurgy
Canadian Diamond Drilling Association

Promotional & lobbying: members are generally companies. The primary purpose is the promotion of the interests of the corporate members, through liaison with and presentations to governments, public relations programs, and provision of information to member companies.

e.g. Mining Association of Canada*
Coal Association of Canada*
Mining Association of British Columbia
Saskatchewan Mining Association*
Mining Association of Manitoba
New Brunswick Mining Association
Ontario Mining Association*
Quebec Metal Mining Association*
Chamber of Mineral Resources of Nova Scotia

* have R&D or technology committees or some other technology-related activities.

Combination - Scientific, Professional & Lobbying: members may be individual or corporate. The purpose combines both professional support and promotion of the interests of the industry. Activities may include technical meetings, public relations, lobbying, provision of information to members. These groups are often more attractive to smaller firms in the industry then the exclusively promotional organizations.

e.g. Prospectors and Developers Association of Canada
B.C. and Yukon Chamber of Mines
Northwest Territories Chamber of Mines
Yukon Chamber of Mines
Association des Prospecteurs du Québec

Research and Development: members are generally mining or metal fabricating companies with a specific commodity focus. Membership is frequently international rather than exclusively Canadian. The research and development activities are designed to improve the producers' competitive position by improving processes and products. Some marketing orientation is usually included.

e.g. International Tin Research Council (ITRC)
Cobalt Development Institute
Tungsten Development Institute
Titanium Development Association
International Lead/Zinc Research Organization
Canadian Steel Industry Research Association
Canadian Asbestos Institute
International Primary Aluminium Institute

Marketing: principally corporate memberships, although government agencies may also be involved. There is generally a commodity-specific orientation. Activities include market research, and educational and promotional activities. R&T and technology interests may also be pursued.

e.g. Potash and Phosphate Institute of Canada
Canadian Copper and Brass Development Association
Nickel Development Institute (also does some R&D)
Association of Tin-Producing Countries (planning merger with ITRC)
Gold Institute
International Precious Metals Institute
International Lead/Zinc Study Group
Ontario Mining Equipment Services for Export Association

Liaison and Advisory: members may be: a) all government representatives, within or between Canadian governments, or at the international level; b) all industry representatives, advising governments; or c) a combination.

e.g. Federal-Provincial Geological Surveys Committee
Federal Interdepartmental Advisory Committee on National Mineral Policy
Federal-Provincial Intergovernmental Working Group on the Mineral Industry

Provincial Mines Ministers
Committee of Provincial Geologists
Canadian Geoscience Council
National Advisory Committee on the Mineral Industry (NACOMI)
Independent Industrial Advisory Committee on Earth Sciences
National Biotechnical Advisory Committee
National Advisory Committee on Mining and Metallurgical Research (NACMMR)

GOVERNMENT ROLE IN THE MINERAL INDUSTRY

Jurisdiction

Formerly under the British North America Act, and since 1982 under the Constitution Act, the provincial governments have ownership of and regulatory power over mineral resources within their borders. They have jurisdiction over regulation of exploration, mining, and primary production, as well as environmental and health and safety, and they levy income taxes, mining taxes, royalties. There are some exceptions to provincial control, such as with respect to uranium, and to minerals on Indian lands, both of which are subject to federal regulation.

The federal government exercises similar (i.e. provincial type) control over minerals in the two territories including the Arctic Islands, and the seabed of the continental shelf. In addition, the federal government regulates some aspects of the mineral industry in all Canada through its jurisdiction over interprovincial and international trade and commerce, fiscal and monetary powers, statistical data collection, navigation, shipping, fisheries, and all undertakings involving more than one province. It also levies personal and corporate income taxes, manufacturers' sales tax, excise taxes, and import tariffs.

A major concern of the mineral industry is the fragmentation of jurisdiction within the federal government in respect of policies for the mineral sector. As shown in table 18, a number of federal government departments perceive that they have policy-making responsibility for various aspects of the industry, and this has led to concern that sometimes conflicting demands are placed on the firms in the industry.

This contrasts with the recent Quebec experience, where an attempt has been made to consolidate policy-making responsibilities for the industry in the Ministry of Natural Resources, in order to develop more consistent and integrated policies in support of the industry in that province. Industry executives have commented favourably on the improved respon-

Table 18

FEDERAL GOVERNMENT POLICY-MAKING DEPARTMENTS WITH RESPECT TO THE MINERAL INDUSTRY

Department	Area of Policy Accountability
Consumer and Corporate Affairs	Competition policy
Employment and Immigration	Manpower assistance and adjustment policies
Energy, Mines and Resources	Policy formulation, advice and information in all aspects of exploration and mining
Environment	Environmental policies
External Affairs	Trade policies
Finance	Fiscal policies, including incentives
Fisheries and Oceans	Water quality policies
Indian Affairs and Northern Development	Regulation and policy for all minerals north of 60
Labour	Health and safety
MOSST	Technology and research and development policies
Regional Industrial Expansion	Funding support and commercialization for further processing, machinery and equipment
Transport	Infrastructure policies

siveness of Quebec to concerns and issues facing the industry since the change was instituted.

All of these federal activities and more are duplicated in each province, in different departmental configurations, with resulting gaps and overlaps in policy-making for the sector.

Federal Mineral Policy

Federal policies affecting the mineral industry have played a crucial role in the development of the industry from its earliest days, and in the

development of the economy in general as a result. Frequently, these policies seem to have evolved in an ad hoc and unplanned manner. Looking back over recent history, Yudelman[19] has identified three major policy thrusts since 1945, beginning with a mineral policy of growth, changing in the 1970s to a policy of redistribution, and evolving at the present into a policy of "managing maturity" (i.e. management of a mature industry).

In the period 1945-70, federal policies encouraged growth in the mineral industry through a wide range of programs, including tax incentives and holidays (e.g. 3-year tax holiday for each new mine), and the provision of infrastructure, such as railway lines, airfields, and the St. Lawrence Seaway. The 1970s shift to redistribution centred on tax reform issues, and began to transfer more of the costs of environmental protection and health and safety to the industry. Throughout both periods, government's role in the industry, in terms of both direct participation and regulation, continued to grow.

In the present period, government is moving towards "maturity management" for mining. There are pressures, both political and economic, for backing away from special incentives and from across-the-board subsidization for any economic sector. This does not preclude, however, assistance in adapting to technological change or other short-term adjustment programs.

Federal Government Activities in Support of the Mineral Sector

Since the Canadian industry is spread across the whole country in terms of production, and is international in terms of markets and competitive position, the focus of a number of research and information programs must also, of necessity, be national and international. Most federal activities directly related to the mineral industry fall under the jurisdiction of Energy, Mines and Resources (EMR). The major exceptions relate to activities in the Yukon and Northwest Territories, where the Department of Indian Affairs and Northern Development (DIAND) exercises provincial-type jurisdiction.

EMR activities do not relate to the ownership of resources. They are primarily directed at the provision of information, assistance, and services to the industry, as well as providing the government with information on the condition of the industry as input to policy formation. In addition, EMR conducts its own programs of R&D and supports industry R&D programs.

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19. D. Yudelman, Canadian Mineral Policy, Past and Present: The Ambiguous Legacy (Kingston: Centre for Resource Studies, 1985).

Geoscience Activities - Data Collection and R&D

The Earth Sciences sector of EMR provides a broad range of services in geosciences, data collection, surveys, mapping, and provision of information and expertise. Its subdivisions include the Geological Survey of Canada (GSC), the Surveys and Mapping Branch, and the Earth Physics Branch. The GSC devotes some of its resources to R&D in exploration techniques and equipment. The Canada Centre for Remote Sensing (CCRS), which is principally a technology development and demonstration agency, also provides additional data from satellite and airborne sources.

Mining and Mineral Processing R&D

The Research and Technology Sector of EMR, and particularly the Canada Centre for Mineral and Energy Technology (CANMET), undertakes in-house development of new technology in mining, mineral processing, and metals utilization, and funds external R&D activities. CANMET's mining-related subsections include: Technology Information, Technology Transfer, Mineral Sciences (including processing and extractive metallurgy), Physical Metallurgy Research, Mining Research, and Coal Research. This sector also provides a technical information base for national health and safety concerns and industrial standards and certification.

Marketing and Economic Studies

The Mineral Policy Sector of EMR keeps track of the status of the Canadian industry, in terms of reserves, production, exports, markets, international trade, economic conditions, human resources, taxation, transportation and the general social, political, and economic environment in which the industry operates. Its information and analysis are available to the public, the industry, and government policy makers. This sector also negotiates federal-provincial mineral development agreements, participates in overseas trade missions and consultations, and supports Canadian research organizations such as the Asbestos Institute and the Centre for Resource Studies.

Infrastructure

Federal programs in several departments, but particularly Transport, affect the mineral industry through the regulation of transportation, the

provision or subsidization of transportation infrastructure, and the operation of transportation companies and services.

Railways

Railways have been particularly important to the mineral industry, which moves large quantities of high-bulk low-value concentrate and products either to processing facilities and markets in Canada or to tidewater for export. The industry, in turn, has been very important to the railways. Between 1945 and 1972, almost all new railroad construction in Canada, about 3500 miles of branch line, was undertaken expressly for the mineral industry, with federal funds covering more than 25 percent of the costs.[20] More recently, federal assistance has been provided for rail and port facilities in British Columbia for the northeast coal development. In 1984, crude minerals represented 48 percent of the revenue tonnage moved by Canadian railways, and fabricated mineral products added another 10.3 percent.

Seaway

Construction of the St. Lawrence Seaway permitted exploitation of the iron ore of the Labrador Trough, much of which is shipped to steel mills in central Canada and USA. In 1983, 10.2 million tonnes of iron ore passed through the Montreal-Lake Ontario section, representing about 22 percent of total shipments. Mineral products as a whole accounted for about 45 percent of all tonnage on the Welland Canal section in 1983, down from the peak of 69.6 percent in 1968.

Ports

At Altantic ports, crude and fabricated mineral products made up 49 percent of tonnage loaded in 1982; Pacific coast loadings were 8.6 percent in 1982, but are rising considerably with rising coal exports.

Transportation costs are a significant factor in the competitive position of Canadian producers, because of the very large distances often involved as well as the total volume, diversity, and geographic spread of Canadian mineral production. For example, Canadian coal delivered to

20. M.J. Wojciechowski, Federal Mineral Policies 1945-75, (Kingston: Centre for Resource Studies, 1979), p. 17.

Japan from the new northeast developments in B.C. cost $76.4 dollars per tonne (U.S. dollars, late 1983) of which rail costs contribute $17.7 per tonne, ports costs add $3.1, and freight to Japan adds $5.5.[21] From the new mines in Queensland, Australia, comparable figures are: $53.4 per tonne CIF Japan, $7.6 for rail, $3.9 for ports costs, and $6 per tonne for freight, for a total advantage for the Australian coal of almost $6 per tonne attributable to transportation costs alone. Although the Australian costs are considerable higher per ton/mile, the distances that the Canadian coal must be shipped are much greater.

Provincial Activities Affecting the Mineral Sector

As noted, provinces own the resources within their borders, and regulate their exploitation through disposition of exploration and mining rights and regulation of mining and processing activities. They are responsible for regulation of health and safety, environmental protection, working conditions, etc. They can legislate on matters relating to mineral conservation, sale of resources within Canada, and direct and indirect taxation of mineral industry revenues.

Provinces also provide services to the industry, such as geoscience data, maps and reports, and mineral industry information. They offer incentives to the industry, through their taxation regimes, some direct subsidies, research and development assistance, and infrastructure assistance.

Among the provinces, only Quebec has a wholly government-owned R&D agency dedicated exclusively to the mineral industry. Ontario has several Technology Centres with interests related to mining, and Alberta supports the Coal Research Centre. With these exceptions, the provinces have played a relatively small role in the pursuit of mineral-related R&D and innovation. For more information on specific provincial programs related to R&D, see chapter 3.

Taxation

The mining industry pays the standard range of federal and provincial income and sales taxes, as do all industrial sectors. In addition, the provinces, as owners of the resources, impose mining taxes or royalties,

21. D.W. Barnett, "Rail Freight and the Cost of Australian and North American Export Coal", Journal of Administration, vol. 15, 1984/85, table 2.

in some cases based on production volume rather than profit. Taxation has been a long-lasting source of concern to the mining industry, in spite of incentives offered through a wide variety of federal and provincial allowances, deductions and credits. The major problems identified by industry, academic, and government representatives at a recent seminar on taxation in the Canadian mining industry were:[22]

- the total burden of taxation (including mining-specific taxes and royalties, as well as non-profit taxes);
- the complexity (due to mining-specific special provisions such as accelerated capital cost allowances, resource allowance, property acqusition provisions, exploration and development deductions, depletion special, flow-through provisions, processing allowances etc.);
- instability (e.g. in provincial income tax or mining tax regimes, major changes were introduced or under consideration in 1985 in B.C., Alberta, Saskatchewan, Ontario, Quebec, New Brunswick, and Nova Scotia);
- rapid growth in nonprofit taxes and government-mandated costs (e.g. workers' compensation, property taxes, utility costs, payroll tax, water tax in B.C. etc.);
- economic inefficiencies (due to incentives that in fact distort economic decisions on the development of marginal deposits);
- inequities (e.g. with respect to risk, or in treatment of companies with no cash flow or with prolonged periods of negative cash flow vs. those with taxable income).

In addition to the cash-flow constraints introduced by taxes, particularly those that are not profit-based, several other tax-related problems affect technological innovation capabilities of the industry. For example, a major one results from the fact that R&D incentives under the corporate income tax rules do not apply to activities that are part of the production process. Since a large part of the development of new mining techniques and equipment must take place in an actual mining setting, rather than a laboratory, much of the cost of innovations in the industry is not eligible for the tax incentives. In addition, federal tax auditors have begun to interpret the definition of R&D very narrowly, according to some industry R&D managers. For example, a recent thrust appears to be the disallowing of a "systematic investigation or search carried out in a field of science or technology by means of experiment or analysis" (regulation 2900) as merely "routine testing", regardless of the degree of uncertainty involved.

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22. M.J. Wojciechowski, ed., Taxation in the Canadian Mining Industry, Proceedings No. 17 (Kingston: Centre for Resource Studies, 1985).

UNIVERSITY ROLE IN THE MINERAL INDUSTRY

Teaching

Canadian universities provide the industry with skilled manpower resources, turning out a steady stream of undergraduates and graduates with a broad range of skills, both managerial and technical. Unfortunately, this "steady stream" may be reduced to a trickle in the near future, if enrollment in mineral-related departments continues to fall due to declining employment opportunities in the mineral industry.

Table 19 shows the number of universities across Canada with departments of programs related directly to some technical aspect of the mineral industry, and the number of degrees granted in 1984. Because of the focus of this study, only science and engineering departments are included. This is in no way intended to underrate the importance of economic, financial, business, marketing, and other management skills to the mineral industry.

Table 19

MINERAL-RELATED UNIVERSITY PROGRAMS AND DEGREES GRANTED, 1984

	Number of Universities	Undergraduate Degrees	Graduate Degrees
Geology: Arts and Science	32	887	332
Geological Engineering	9	281	5
Geophysics	16	116	45
Mining Engineering	8	136	39
Mineral Processing	6	20	11
Metallurgical Engineering	10	136	95
Metallurgical: Arts and Science	2	25	3

In addition to the university programs, there are 17 technical schools and colleges offering courses in mineral-related technologies. In 1984 they graduated 716 students in mineral-related fields (including 153 in oil and gas technologies).

Table 20 shows the number of degrees granted over the period 1970-86, and table 21 gives the distribution of undergraduate degrees by discipline since 1981.

Table 20

GRADUATES IN MINERAL-RELATED SCIENCES AND ENGINEERING, 1970-84

Year	Technology	Bachelor	Master	Doctorate	Total
1970	293	501	174	64	1032
1971	368	657	237	85	1347
1972	486	857	201	88	1632
1973	388	906	241	102	1637
1974	403	983	226	83	1695
1975	317	903	259	79	1558
1976	304	740	232	89	1365
1977	330	719	253	85	1387
1978	364	734	191	78	1367
1979	402	736	214	65	1417
1980	500	831	189	60	1580
1981	517	1095	257	83	1952
1982	794	1224	270	81	2369
1983	795	1368	281	72	2516
1984	716	1127	349	94	2286

Source: Education Survey, CIM Bulletin, July 1982, September 1983, August 1984, and November 1985.

Table 21

UNDERGRADUATE DEGREES GRANTED, 1981-86

Year	Geology, Geo.Eng. and Geophysics	Mining Eng.	Mineral Processing	Metallurgy and Met. Eng.
1981	815	97	27	134
1982	989	123	16	125
1983	1265	125	21	141
1984	1164	116	21	150
1985	1286	100	20	150
1986	n.a.	89	19	133

Source: Education Survey, CIM Bulletin, July 1982, September 1983, and November 1985.

n.a. = not available

Research and Development

Universities are generally considered to be the principal agencies for performing basic research and long-term applied research and development in all fields. This is curiosity-motivated research, the sort of research that pushes forward the frontiers of knowledge and that, in time, makes possible revolutionary breakthroughs in technology and innovation. Basic R&D continues to be funded and pursued actively in a number of earth sciences or geology departments across the country. For mining and metallurgy, however, there are few researchers in basic fields or long-term applied R&D in university departments. Much of the R&D in these departments is on a contract basis, directly linked with the industry, applied or problem-related in nature, and relatively short term in focus. In many cases, the results are confidential and do not lead to generally-available publications.

There is a growing recognition of potential for Centres of Strength or Centres of Excellence in the mineral field at Canadian universities as a means of combatting the catch-22 problem of "few grants for research because few applicants for grants because few grants for research". Such centres would draw on the talent of a number of universities, focus attention on specific problem areas, build up a "critical mass" of expertise that would hopefully have a synergistic effect, and attract new funding to support the research efforts. Among the sorts of centres that have recently been established or are under consideration are centres for mineral exploration, open-pit mining, rock mechanics, robotics and automation, and materials technology. As shown in table 22, there already a number of mineral-related institutes and centres associated with university departments. In most cases, however, there are few inter-university links.

Technology Transfer

Universities also have an important role to play in technology transfer from the laboratory to the industry. This transfer process must work in two directions. First, it must draw on advances in other disciplines and adapt them to the needs of the industry. This applies to the so-called "emerging" technologies, such as biotechnology, information technology, and robotics and automation, as well as more traditional fields such as physics, chemistry, and all the engineering disciplines. It will require faculty members and researchers in mineral-related departments to follow developments in a variety of fields, and engage in interdisciplinary joint ventures when areas of mutual interest have been identified. There are

Table 22

UNIVERSITY CENTRES AND INSTITUTES

University	Affiliated Research Institute
Laurentian University	Centre for Mining and Mineral Exploration Research (CIMMER)
Memorial University	Centre for Earth Resources Research (CERR)
Ottawa/Carleton University	Centre for Geoscience Studies
Queen's University	Advanced Materials Technology Unit
Technical University of Nova Scotia	Laboratory for Investigation of Minerals
Université du Québec a Chicoutimi	Centre d'études sur les ressources minerales
Université du Québec a Montréal	Laboratoire de géochemie isotopique et de géochronologie (GEOTOP)
University of British Columbia	Centre for Metallurgical Process Engineering
	Coal Research Centre
University of Calgary	Alberta Sulphur Research
	Coal Mining Research Centre
University of Manitoba	Centre for Precambrian Studies
University of Ottawa	Derry Laboratory for Sedimentary and Mineral Deposits

Note: Information was taken from university calendars, and is not complete coverage of all such centres and institutes.

severe constraints to interdisciplinary technology transfer, including the sheer volume of published material and information that could conceivably be drawn upon, the traditional departmental structure, and the difficulty of obtaining funding for interdisciplinary research projects.

Second, universities must play a much greater role in transfering technology into commercial applications in the private sector. This can be done through one-on-one contracts for services, joint-venture research

projects, publications and presentations, by organizing meetings, seminars, spcialized centres, and other opportunities for interchange of ideas. Much progress has been made in these activities in recent years.[23] However, much remains to be done by university researchers, both in technology transfer per se, and in convincing the private sector of the contribution that universities can make to technological innovation.[24]

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23. See for example Paul Dufour and Michael Farley, "The Role of Canadian Universities in Technology Development", CIM Bulletin, October 1986.
24. See for example, D. Bevelander, "Barriers to Innovation in the Mining Industry", in M.J. Wojciechowski, ed., Technology Policies in the Canadian Mineral Industry, Proceedings No. 19, (Kingston: Centre for Resource Studies, 1986), pp. 59-63.

Chapter 3. RESEARCH AND DEVELOPMENT FUNDING SOURCES, LEVELS, AND ACTIVITIES

RESEARCH AND DEVELOPMENT

Continuing technological innovation in industry requires a comprehensive research and development effort, as well as design and demonstration aimed at industry needs, commercial production, and sales. While chapters 5-10 will consider all phases of innovation, this chapter will focus principally on research and development, for several reasons:

- most important, because the level of R&D effort is an indication of the commitment of a firm, sector, or country to technological innovation;
- R&D activity facilitates transfer of technology that has been developed in other sectors or jurisdictions;
- Statistics Canada figures are available for R&D activities, both for expenditures and sources of funds (unfortunately, in many cases the various series are not directly comparable);
- development, design, and demonstration expenditures are not available on a sector-wide basis;
- except in the field of geophysics, there has been relatively little commercialization of Canadian-developed innovations in equipment for the mineral industry.

Even those figures that are available from Statistics Canada on R&D do not give a complete picture. For a variety of reasons, including the definition of R&D for taxation purposes, reported R&D figures are lower in many cases than actual industry R&D expenditures in new technology and equipment. In other cases, they may be higher than they should be because they include engineering and development work that are part of standard operations. In 1985, according to CANMET officials, who were then in the process of developing an index of mining technology development, "it is simply not possible to make any definitive statements concerning the state of mining research in Canada... it must be stressed that the total involvement of the industry is unknown".[1]

1. J.E. Udd and R.J.R. Welwood, "Towards Determining the Extent of Mining Research in Canada", paper presented at CIM Annual General Meeting, Vancouver, April 1985. The Index of Mining Technology Projects has since been published by CANMET (1986), but it gives no expenditure information.

Simple dollar measurements of R&D expenditures give an indication of financial commitment to technological efforts. However, absolute figures can be misleading, as mentioned above, or when used in comparisons between countries or over time because of variations in currency values or price levels. They can also be misleading if used to make comparisons between sectors, or firms within sectors, because of differences in technological requirements, economies of scale, size of firms, etc.

It is therefore helpful to look at R&D in the mineral sector in a variety of ways: e.g. expenditure dollars; expenditures in relation to some other variable such as revenues, sales, or profits; expenditure rates in comparison to other sectors; sources of R&D funding; areas of concentration in the visible results such as published papers or patents; who is doing the R&D; firm-specific R&D projects and activities; and general attitudes towards research, development, and innovation.

This chapter will give a brief summary of published information on research and development in mineral-related research activities in government and industry. It omits discussion of university research, because the focus of the chapter is primarily funding sources and levels. Since universities are not funding sources in themselves, inclusion of their programs would in effect be double-counting of total funding levels.

OVERVIEW OF R&D FUNDING LEVELS

There are strong reasons to believe that R&D in the mineral sector in Canada is not as well funded as it should be. Internationally, Canada falls behind a number of its major mineral industry competitors in terms of level of overall industrial R&D expenditures as a percent of domestic product of industry, as shown in table 23.

Table 23

INTERNATIONAL COMPARISON OF INDUSTRIAL R&D EXPENDITURES, 1975 and 1981

	R&D Expenditures/Domestic Product of Industry				
	1967	1975	1981	1982	1983
Sweden	1.3	1.6	2.3	-	2.6
W. Germany	1.3	1.6	2.2	2.3	2.3
USA	2.4	1.8	2.0	2.2	2.2
Japan	0.9	1.3	1.6	1.7	1.9
France	1.4	1.4	1.5	1.6	1.6
Canada	0.7	0.6	0.8	1.0	0.9

Source: Statistics Canada, Industrial R&D Statistics, Cat. 88-202, various years.

To make matters worse, mining is not one of better funded sectors in R&D in Canada, as shown in table 24 below and appendix table A14. Furthermore, the rate of increase in R&D expenditures has been much smaller for Canadian mining than, for example, for oil and gas (see appendix table A13).

This relatively low level of R&D funding in mining is not unique to Canada. For example, figures prepared by the U.S. National Science Foundation (see appendix table A14) comparing R&D intensity[2] in U.S. industries ranked ferrous metals at the bottom, on a par with textiles and lumber and wood products in 1960 at 0.6 percent, increasing to 0.8 percent by 1981. Nonferrous metals were slightly better, at 1 and 1.2 percent, and fabricated metals reached 1.4 percent in 1981. These figures

Table 24

CANADIAN CURRENT R&D EXPENDITURES IN SELECTED INDUSTRIES

Industry	Current $ million				Current R&D as % of Company Sales	
	1983	1984	1985	1986	1983	1984
Mining	39	43	45	47	0.8	0.7
Gas & oil wells	33	50	52	53	0.6	0.7
Manufacturing						
Rubber & plastics	16	16	18	19	0.8	0.8
Wood-based	14	16	16	17	0.5	0.8
Ferrous metals	21	27	25	26	0.3	0.4
Non-ferrous primary metals	77	86	97	105	1.2	1.3
Business machines	115	137	157	170	2.7	2.7
Aircraft & parts	266	266	319	358	17.3	15.2
Communications equipment	359	423	532	596	13.2	13.6

Source: Statistics Canada, Industrial Research and Development Statistics, cat. 88-202.

Note: except for gas and oil wells, which averaged as high as 50 percent, capital R&D expenditures were relatively small, averaging from 5 to 20 percent of current R&D expenditures.

2. Defined as total R&D funding as a percent of net sales.

contrast sharply with those for several of the U.S. industries in growth markets that have shown a long-term dependence on R&D, such as aircraft and parts, electrical equipment, office and computing machinery, and drugs, which ranged from 22.5 percent to 6.4 percent. These industries are all consumer-oriented, with a higher emphasis on added value in the final product. These figures, as well as some in table 24, reflect the surges in R&D expenditures that are characteristic in the early stages of innovation in growth and high-tech industries, but generally not found in mature industries or in resource industries such as mining.

The principal source of reported funding for mineral-related R&D in Canada is the federal government, followed by the industry itself. In 1986, for example, mining and metals companies reported spending a total of $178 million (see table 24) while EMR spent $286 million on in-house R&D plus external R&D support in fiscal year 1985/86. Some additional federal funds were provided under assistance programs not specific to mining, and some provincial government funds were provided as well, particularly in Quebec and Ontario.

FEDERAL GOVERNMENT PROGRAMS

Energy Mines and Resources

Federal activities in support of R&D in the mineral sector include both active in-house R&D programs and financial support for external R&D activities. The in-house programs are concentrated in EMR and, within EMR, in the Canada Centre for Mineral and Energy Technology (CANMET). R&D is also performed by the Geological Survey of Canada, where the primary mandate is the collection, analysis, compilation and publication of geoscience data, but which also devotes resources to research in basic geoscience theories and in development of instrumentation and techniques for mineral exploration. In addition, the Mineral Policy Sector of EMR does some research in mineral economics, markets and consumption trends.

EMR's Science and Technology (S&T) budget includes, in addition to R&D, information gathering such as geological surveys, testing, and a variety of other related scientific activities. R&D has constituted about 70 percent of the S&T expenditures in recent years, as shown in table 25. Table 25 also indicates that the major portion of the S&T funds are spent intramurally, although the share has decreased noticeably in recent years.

Table 25

EMR FUNDING OF R&D

	1979/80	80/81	82/82	82/83	83/84	84/85	85/86
R&D Funding[a] ($ million)	107.3	124.7	153.5	170.4	193.2	254.1	286.1
S&T Funding ($ million)	152.7	194.2	232.2	256.6	288.7	368.8	433.2
Distribution of S&T Funds (percent)							
EMR intramural	68	67	70	78	73	70	66
Industry	9	14	13	13	16	19	24
University	1	2	2	2	3	2	2
Prov. govt	20	15	14	3	6	5	2
Other	2	2	2	4	3	4	6

Source: adapted from Statistics Canada, Federal Scientific Activities, 1985/86, Cat 88-204E, February 1986.

[a] R&D funding is a subset of science and technology (S&T) funding, which also includes such activities as data collection, testing, education support, and related scientific activities.

EMR Intramural R&D

EMR's in-house R&D is concentrated within CANMET and its laboratories, and in the GSC. It tends to be applied research but of a more long-term nature and of more general interest than R&D done within the industry. Decisions on R&D priorities and allocation of funding are made within the federal government. Industry input is received through advisory committees such as NACMMR (National Advisory Committee on Mining and Metallurgical Research).

Activities can generally be described as concentrating on the research end of the spectrum, rather than the development end, in part because mining equipment is excluded from EMR's mandate. However, the development and demonstration end of both process and equipment innovation are far costlier than the research stage. At present, the major burden for these activities is left to the private sector and is, for the most part, conducted outside Canada.

Of EMR's total S&T funding, almost 69 percent goes to the Mineral and Earth Sciences Programs, and the remainder to the Energy Program. Among EMR's S&T agencies, 1982/83 funding was allocated as follows:

- CANMET - $40.0 million;
- Earth Physics - $12.0 million;
- Surveys and Mapping - $19.8 million;
- Geological Survey of Canada (GSC) - $48.5 million;
- Canada Centre for Remote Sensing - $18.5 million.

In 1986, Earth Physics merged with the GSC.

In 1985/86, EMR's principal in-house R&D expenditures within its S&T funding program for the mineral industry were approximately as follows.

Geological Survey of Canada:

for R&D in mineral exploration data collection and technology for metallic and nonmetallic deposits, including coal and uranium:

- geological technology - $14.3 million
- geophysical technology - $6.3 million
- geochemical technology - $0.68 million

CANMET:

for mineral technology, excluding oil and gas but including coal and uranium, and including Mineral Development Agreement funding and external contracts:

- mining	$ 5.5 million
- coal mining and preparation	$ 6.0 million
- mineral processing	$17.7 million
- metals and materials	$10.2 million

CANMET's program of R&D is concentrated in its Ottawa laboratories, which include:

- the Mineral Sciences Laboratories - chemical, mineral processing and extractive metallurgy;
- the Physical Metallurgy Research Laboratories - metals development and metals processing;
- the Mining Research Laboratories - explosives research, explosive atmospheres, and rock mechanics.

In addition, there are coal research laboratories in Edmonton and Cape Breton, and a mining research laboratory in Elliot Lake. A listing of CANMET projects under way or under consideration is given in appendix C.

In 1983, CANMET officials estimated that approximately 35 percent of its R&D expenditures were related to health, safety, and environmental protection.

EMR Extramural R&D Support

In addition to intramural R&D activities, EMR also provides funding for R&D programs conducted by researchers in industry, universities, and provincial government facilities. As table 25 indicates, industry's share has increased from 9 percent to 24 percent of S&T funding since 1979. The provincial governments' share of EMR funding dropped with the expiry of the old Mineral Development Agreements, and picked up again in 1983/84 as the new agreements began to go into effect. Of the grants to universities, approximately 20 percent are for mineral research, 47 percent are for earth sciences studies, and the balance are for energy-related projects.

Federal/Provincial Mineral Development Agreements

Ten mineral development agreements have been signed with provinces and territories since 1983, and most include a program called Mining and Mineral Technology. This funding will be incorporated into the budgets of EMR. The technology programs will receive federal funding at the following level, over a 5-year period:

Newfoundland	- 50 percent of $2.1 million
Nova Scotia	- 60 percent of $5 million
New Brunswick	- $3 million
Quebec	- 50 percent of $8 million (asbestos R&D)
Ontario	- 50 percent of $3.55 million
Manitoba	- 60 percent of $7.43 million
Saskatchewan	- $400,000
British Columbia	- small technology component
Yukon	- small technology component

More than 90 percent of the technology funding is contracted out, under the guidance and management of CANMET. Federal R&D projects under the agreements include mining technology (rocky mass behaviour, delay backfill, vertical block method mine design, geomechanical data base, optimization blast design, and potash backfill); communication (underground person-to-person communication for safety purposes); beneficiation (metallic and industrial minerals, milling, pelletizing, and

metallurgy studies); extractive metallurgy (gold, ferric chloride leach, manganese, pyrrhotite rejection, GCM process); and byproduct recovery (gold and silver recovery from leach residues).

Other Federal In-House R&D Programs

There are several federal R&D programs outside of EMR which support the activities of federally owned or regulated mineral production facilities. For example, Eldorado Nuclear has an R&D division with programs in process technology and environmental and worker protection, and Atomic Energy Canada Ltd. supports R&D in areas of environmental protection and health and safety connected with uranium mining.

Other Federal R&D Funding Programs

Other federal government programs supporting R&D which are available to the mineral industry, although aimed at all sectors, are available from a number of departments and organizations in addition to EMR.

Department of Supply and Services (DSS)

Unsolicited Proposals Program - CANMET has drawn heavily on this program to obtain funding support for industry for a variety of mineral, mining and mining-equipment related projects. The programs are industry-driven, in the sense that government departments cannot access the funds directly, nor impose their own priorities or preferences on the subject matter or timing of submissions.

CANMET accesses something over $1 million each year from this DSS program, about 10 percent of the program total. This funding is over and above CANMET's own budget. The major proproportion of these funds, over 75 percent, goes to projects in mineral processing and metallurgy.

Department of Regional Industrial Expansion (DRIE)

IRDP - Industrial and Regional Development Program, the core of DRIE's assistance to industry. Its program elements include Industrial Development Climate, Modernization/Expansion and Marketing. The Innovation element, which included technology transfer, industrial design and pollution abatement technology, has been dropped. 1984/85 funding was $110 million.

DRIE programs are generally for industrial development and commercialization rather than R&D. DRIE programs specifically exclude mining and have seemed to effectively exclude many mining equipment applications as well.

National Research Council (NRC)

IRAP- The Industrial Research Assistance Program has been NRC's main source of funding for industrial R&D. The program has been well received by industry. The Large Projects element was transfered to PILP (below) in 1985. 1984/85 funding was $48 million, but some was transfered to the PILP program. IRAP has been a significant source of support for the mineral industry and its suppliers.

PILP - The Program for Industry/Laboratory Projects is also administered by NRC. (In 1986, renamed IRAP Laboratory Network.) It is designed to promote technology transfer from government and university laboratories to industry. Criteria include the probability of a high economic return through commercialization of the research results. A biotechnology program has been established within PILP, to link academic research with the growing biotechnology industry. The 1984/85 budget was $29 million. PILP has provided substantial funding for mining-related projects.

National Sciences and Engineering Research Council (NSERC)

PRAI Grants - Project Research Applicable in Industry. This program was administered by NSERC, and was designed to facilitate developments arising out of university research, and their transfer to the industrial sector. It was replaced in 1985 by CRD Grants.

CRD Grants - Cooperative R&D grants program. In 1985/86, CRD grants for mineral-related university-industry joint projects totalled $816,000.

Operating Grants - In 1985/86, NSERC operating grants for earth sciences totalled about $12 million. For mining (from the civil and chemical committees) grants totalled $295,000, and rock mechanics received $103,000.

Strategic Grants - also an NSERC program, designed to initiate or accelerate substantial projects in areas of national concern. These include biotechnology and energy. In the mineral area, strategic grants in 1985/86 included $183,000 for rock burst studies and

other awards for studies in exploration techniques, toxic and nuclear waste disposal, and mineral processing.

The PRAI and Strategic grants programs had a combined budget of $31.4 million in 1983/84, so it is clear that mineral-related projects, and particularly mining projects, constitute a very small proportion of these programs.

PROVINCIAL GOVERNMENT PROGRAMS

Quebec is the only province with a government-owned R&D facility exclusively for research in mineral technology: the Centre de Recherches Minerale. Ontario and Alberta do some mineral-related in-house R&D through their respective Research Councils. Alberta supports the Coal Research Centre and New Brunswick's Productivity Council is also conducting mineral-related research.

Alberta

In-house programs:

- Alberta Research Council
  - Alberta Geological Survey - geoscience data gathering
  - Terrain Sciences Research - includes reclamation and highwall stability studies
  - Coal Research
  - Mineral Processing Research - metallurgical testing and ore dressing studies

Assistance and Joint Programs:

- Coal Research and Technology Program - funding program for research in enhancing competitive position, in minimizing environmental impact of mining, and in new uses for coal.

- Financial support for the Coal Mining Research Centre - a private corporation for applied research in mining, beneficiation, and health and safety aspects of coal mining.

- Plans are being made for a Coal Reclamation Research Program - a government/industry research program.

British Columbia

In-house Programs:

- Energy Mines and Petroleum Resources
  - Geological Branch - geoscience data and mapping
  - Mineral Policy and Evaluation Branch - marketing studies, mine-head financial simulation studies

Assistance Programs: financial assistance for projects including:

- coal liquefaction
- silver catalyzed biological leaching of copper concentrates
- coal oxidation

Manitoba

In-house Programs:

- provincial share of Canada/Manitoba Mineral Development Agreement, Research and Technology Program - $2.8 million - emphasis on processing technology
- geological services - geoscience data and mapping

New Brunswick

In-house Programs:

- provincial share of Canada/New Brunswick Agreement, Technology program $275,000
- geoscience data and mapping
- New Brunswick Research and Productivity Council - R&D interests include extractive metallurgy

Newfoundland

In-house Programs:

- Canada/Newfoundland Agreement, Technology program provincial share, $600,000
- geoscience data and mapping

Nova Scotia

In-house Programs:

- Canada/Nova Scotia Agreement - provincial share in Technology program $1.6 million
- geoscience data and mapping

Ontario

In-house Programs:

- Canada/Ontario mineral development agreement - provincial share in Technology program $3.4 million
- Ontario Geological Survey - geoscience data and mapping
- Geoscience Data Centre
- Ontario Centre for Remote Sensing
- Ontario Research Foundation - nonprofit industrial research contracts, on a confidential basis. Mineral research has been mainly in the processing field.

Assistance Programs:

- Ontario Centre for Resource Machinery Technology - mining and forestry - identifies manufacturing opportunities and initiates joint ventures, provides advice and equity. OCRMT has 3 main services: technology linkages; venture investment; and prototype research. Its total budget was originally set at $16.4 million, and its investments to 1985 averaged about $230,000.
- Exploration Technology Development Fund - up to $150,000 per grant per year for applied research by consultants and instrument manufacturers, for innovative technology
- Ontario Geoscience Research Program - for university research in geosciences
- Resource Diversification and Development Program - funding for studies and demonstration projects in resource extracting, processing and marketing
- Ontario Centre for Microelectronics - joint ventures with industry in equipment design and development
- Ontario Centre for Advanced Manufacturing - Robotics development

Quebec

In-house Programs:

- geosciences data and mapping
- Centre de Recherches Minérales (CRM). It was established in 1982 to support university research. In 1984, $2.6 million was commited to mineral research in Quebec. Projects may be proposed by eligible companies and conducted by CRM which bears 70 percent of the costs. Gold is a major area of interest, as well as iron ore, industrial minerals and base metals.

Assistance Programs:

- Canada/Quebec Mineral Development Agreement, $4 million for asbestos R&D, with an emphasis on new uses for asbestos
- Ad hoc Assistance Program for Techno-Economic Studies
- Program of Assistance for Technological Development of the Mining Industry Through the Hiring of Specialists
- contracts for geoscientific research, to industry and universities
- reduced rates to industry for CRM services
- investment assistance for research laboratories

Saskatchewan

In-house Programs:

- Canada/Saskatchewan Mineral Development agreement, provincial contribution to Mineral Technology program, $400,000
- Geological Survey Branch geoscience data and mapping
- Saskatchewan Research Council

INDUSTRY R&D PROGRAMS

Introduction and Overview

Industry in-house R&D is generally limited to a relatively small group of large firms, is always applied, and is usually directed toward incremental improvements. In some cases, what may be described as R&D is really routine development and upgrading of equipment and processes. The Canadian mineral industry has made no effort to establish its own industry-wide R&D organizations like the South African Chamber of Mines, Australia's AMIRA, or the Swedish Mining Association's Research Division.

An exhaustive examination of the research programs of individual companies in the mineral industry is beyond the scope of this study. This would require individual canvassing, company by company, since much of the in-house R&D is not included in various statistical reporting procedures because it is integrated into operating departments and expenditures, and/or because the expenditures are not defined as R&D for tax purposes. For the mining sector alone, CANMET's Index of Mining Technology Projects, begun in 1983/84 and first released in November 1986, required two person/years and about $150,000 for the first issue.[3] The index does not include any information an R&D expenditures. As a result of the lack of published detailed financial information, therefore, this section will look at some major indicators published by Statistics Canada and identify those firms that report significantly large active R&D programs.

Table 26 gives a brief picture of the overall level of activity among the 22 firms reporting R&D programs to Statistics Canada in 1983. Most of the programs were small. Although an exact breakdown of program size for mining alone is not available in the Statistics Canada 88-202 publication, the combined category of mines and gas and oil wells showed the following distribution: R&D programs under $100,000 - 7 firms; $100,000 to $999,000 - 15 firms; $1 million and over - 15 firms. (There were 15 firms in the oil and gas industry, and $74 million in R&D expenditures.)

Foreign ownership does not seem to constrain the level of R&D spending by the mining industry; on the contrary, foreign-owned firms spend more on R&D. The industry was approximately 70 percent Canadian controlled in 1983, in terms of assets and sales and 80 percent Canadian in terms of number of companies. Nevertheless, Canadian firms accounted for only half of the number of firms reporting R&D expenditures, and for only 57 percent of the total amount.

As noted, R&D in the Canadian mineral sector is highly concentrated in a relatively small number of large vertically integrated metallic mineral firms. This section will look at the firms listed in table 27 (except Rio Algom), all of which have significant R&D efforts. Not surprisingly, these firms are also the leading metal companies in terms of operating revenues.

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3. J.E. Udd and R.J.R. Welwood, "Towards Determining the Extent of Mining Research in Canada", paper presented at CIM Annual General Meeting, Vancouver, April 1985. Costs are expected to drop for the annual updates, beginning in 1987.

Table 26

INDICATORS OF INTRAMURAL R&D ACTIVITY WITHIN MINERAL COMPANIES, 1983

	Mining	Primary Metals (ferrous)	Primary Metals (nonferrous)
Expenditures ($ million)[a]	41	21	81
Current Expenditures as % of Sales	0.6	0.3	1.3
Number of Firms reporting R&D	22	11	11
Number of person/years in R&D:			
Professionals	285	160	375
Technicians	270	95	425
Other	75	55	220
Total	635	310	1,020
Professional person/years by degree level:			
Bachelor	180	115	180
Master	40	30	95
Doctorate	65	15	100
Payments for Foreign Technology ($ million)	14	8	n.a.

Source: Statistics Canada, 88-202.

[a] If all-in personnel costs are assumed to be $50K/py, then expenditures over and above personnel costs can be estimated to be about $9.25 million for ferrous, and $30 million for nonferrous. In other words, these were the funds available for capital and equipment expenditures in these high-capital-cost areas of applied R&D.

Table 27

CANADA'S LEADING METALS COMPANIES, IN TERMS OF OPERATING REVENUE, 1985
($ million)

Company	Operating Revenue	Net Income (Loss)	R&D Expenditures	Total Assets
Alcan	7,806[a]	(295)[a]	77[b]	6,861
Noranda	3,439	(71)	10	6,241
Inco	2,034	71	22	3,083[b]
Cominco	1,458[a]	(71)[a]	4[b]	2,056
Rio Algom	1,227	88	n.a.	1,834
Falconbridge	890	39	n.a.[c]	1,351
Denison	737	(158)	n.a.	1,724
Sherritt Gordon	445	(5)	n.a.	651

Sources: Financial Post 500, Summer 1985, and annual reports for R&D figures.

[a] converted from U.S. dollars.

[b] in U.S. dollars.

[c] 1984 R&D expenditures were $3.2 million.

Alcan Aluminium Limited

Alcan, worldwide, is the largest single producer of aluminum. Total production in 1984 amounted to 1,790,000 tonnes, of which just over 1,000,000 tonnes is produced in Canada. Alcan is vertically integrated, from the smelter stage within Canada, and derives over 60 percent of its income from the sale of fabricated products. Canadian operations account for approximately 50 percent of total Alcan revenues and profits.

Alcan has made a strong commitment to new technology, allocating increased funding to research and development over the last five years, in spite of depressed earnings, a commitment that is reflected in the continuing increase in R&D expenditures in the face of falling earnings. Alcan's spending on research and development is more than double that of all the other Canadian primary metal producers combined, although of course only part of Alcan's R&D is conducted in Canada.

Table 28

ALCAN FINANCIAL DATA, 1980-84
($ million U.S.)

	1980	1981	1982	1983	1984	1985
Net sales	5,264	5,053	4,709	5,305	5,576	5,831
Net earnings	542	264	(58)	73	253	(180)
R&D expenses	n.a.	n.a.	55	60	66	77
Long term debt/equity	0.35	0.60	0.68	0.52	0.47	0.58
Total assets	5,485	6,346	6,632	6,600	6,690	6,861

Source: Alcan Aluminium Limited, Annual Report, 1984, 1986.

Research and Development Organizations

R&D is organized within Alcan International Limited, Alcan's technology management company - total employment 1,000. Facilities include the following.

Arvida Laboratories: staff of 185, with 47 scientists and engineers.
Kingston Research Centre: staff of 350, with 140 scientists and engineers.
Banbury Research Centre (United Kingdom): staff of 200, with 80 scientists and engineers.
Affiliated research centres in Japan (NKK) and India.

Research Interests

Alcan's substantial research and development budget permits a significant amount of work to be done on a number of major technical developments, such as the development of new reduction and continuous rolling processes, as well as some significant product developments. Alcan devotes a substantial proportion of its annual technology budget to piloting these new technologies. Examples include:

- reduced costs and improved efficiences and recoveries in raw materials;
- new processes for alumina reduction;
- decreased energy and capital intensity in reduction;
- development of improved-hygiene reduction processes;
- improved fabrication technologies;
- new aluminum alloys, e.g. aluminum-lithium alloys;
- new aluminum products, e.g. computer memory discs;
- new applications for existing products, e.g. automobile parts;
- related product diversification, e.g. gallium arsenide semi-conductors.

Noranda Inc.[4]

Noranda Inc. is a large, diversified natural resources company, with interests in oil and gas (principally Canadian Hunter), forest products (Fraser Companies, MacMillan Bloedel, and MacLaren Inc.), as well as mining and metallurgical operations. Noranda is the largest zinc producer in the world, operates the largest copper smelter and refinery in North America, and is also a producer of a broad range of other base and precious metals. Noranda is also integrated forward in Canada and the United States into a number of metal fabrication businesses.

Noranda's aggregate financial results from 1980 to 1984 are shown in table 29 below. With the exception of 1982, revenues have grown through the 5 years, but record profits in 1980 have been replaced by three years of losses. Metals and minerals comprise approximately 30 percent of

4. As of January 1986, all of Noranda's mineral-related businesses were consolidated under a new company name, Noranda Minerals Ltd.

Table 29

NORANDA INC. CONSOLIDATED FINANCIAL DATA 1980-85
($ million Canadian)

	1980	1981	1982	1983	1984	1985
Revenues[a]	3,400	3,106	2,830	3,030	2,889	3,462
Earnings (loss)[a]	416	169	79	25	5	(71)
R&D expense[b]	n.a.	n.a.	n.a.	9.4	9.6	9.8
Total assets	3,938	5,249	5,705	6,131	6,306	6,241
Long-term debt/equity	0.29	0.32	0.63	0.77	0.88	0.92

Source: Noranda Mines Limited, Annual Report, 1984.

[a] Noranda Inc. metals and mineral segment:

	1984	1985
revenues	1,014	1,022
operating profit	75	46

[b] Budget of Noranda Research Centre.

Noranda's total revenues in the last two years, but contribute over half the company's operating profit, in spite of recent depressed prices for these products. The company's research and development budget has remained relatively stable at around $10 million for the last five years.

Research Interests

- improved recoveries and productivity, in mining - e.g.:
  - in-situ leaching of copper from an oxide orebody
  - design and monitoring of safer underground openings
  - backfill studies, including the use of ice as fill
  - development of CAD system for mine design, using PCs
  - development of more convenient ground-monitoring instrumentation
- in processing and smelting improvements in quality, reductions in cost e.g.:
  - higher quality selenium
  - new lower-cost treatment for gold mud
  - higher quality cathodes from impure anodes
- new business opportunities - e.g.:
  - development of high performance zinc aluminum casting alloys
  - commercialization of hydrogen technology
  - electro-optic materials, including for solar cells and digital imaging systems

Inco Limited

Inco Limited is the world's largest producer of nickel, and its integrated operations include mining, smelting, refining, and marketing of nickel in a wide variety of forms. Inco also produces, refines and markets a number of other metals from its Canadian ores, including gold, copper, platinium group metals, and small quantities of cobalt, silver, sulphur, selenium and tellurium. In addition to its Canadian nickel mines at Sudbury and Thompson, Inco has an active production facility in Indonesia and a mothballed facility in Guatemala. The company produces and markets a wide range of nickel and nickel alloy products, and has active exploration programs for a variety of minerals as well as oil and gas.

The company has active research programs, in mining and in metallurgy. The Copper Cliff North mine in Sudbury has been turned into a research mine, with bulk mining, continuous methods, and productivity improvements as the principal areas of interest. The J. Roy Gordon Laboratories at Sheridan Park conduct research principally in the field of extractive metallurgy. New product research has fallen off sharply since the closing of Inco's Sterling Forest facilities in the USA in 1981.

Table 30

INCO FINANCIAL DATA 1980-85
(U.S. $ million)

	1980	1981	1982	1983	1984	1985
Net sales	2,150	1,886	1,236	1,173	1,468	1,491
Net earnings (loss)	232	(470)	(203)	(235)	(77)	52
R&D expenses	34	37	35.8	29.4	22.4	21.9
Total assets	4,721	3,856	3,473	3,183	3,110	3,083
Long-term debt/equity	-	0.83	0.93	1.03	1.15	0.87

Source: Inco Ltd., Annual Report, 1984.

Research Organizations

J. Roy Gordon Research Laboratories: hydrometallurgy, pyrometallurgy, and electrochemical extractive metallurgy, plus process design and other services.
Port Colborne Pilot Plants - for process testing and development.
Copper Cliff North Research Mine - vertical crater retreat mining methods and equipment.

Inco has established Continuous Mining Systems Ltd. to develop, manufacture and market mining equipment for bulk and continuous methods, and also belongs to HDRK Mining Research Ltd. and the Nickel Development Institute, both of which are industry joint ventures. It has also entered a joint venture with Spar Aerospace to develop remote controlled underground mining equipment to improve safety and productivity. The first project in this venture is a remote machine for bolting and screening.

Research Interests

Inco's major research interests at present are in 2 areas:

- mining productivity improvements, using bulk and continuous methods;
- new plant design for extractive metallurgy, aiming primarily at reduced SO_2 emissions, plus reduced manpower and energy requirements, improved metal credits, and minimal capital costs.

The list of projects in progress is both wide-ranging and extensive.

Research Expenditures

Inco's Canadian R&D expenditures are shown in table 31.

Table 31

INCO'S CANADIAN R&D EXPENDITURES, 1980-84
($ thousand)

	1980	1981	1982	1983	1984
Laboratory-Process	3,715	4,158	4,308	4,038	4,350
Pilot Plant-Process	5,768	6,380	6,616	3,888	4,071
Process Development	945	1,057	948	700	584
Geology & Exploration	646	730	791	818	560
Within Divisions	8,060	8,392	6,820	7,084	10,796
Seed & Other	710	2,075	1,306	197	389
Total	19,844	22,792	20,789	16,725	20,750

Note: These figures are for Canada only, so the totals do not match the R&D expense figures in table 30, which apply to Inco's operations worldwide, including subsidiaries.

Falconbridge Limited

Falconbridge Limited is the world's second largest nickel producer with a 14-percent market share. In addition to its nickel mines in Sudbury, Falconbridge owns a ferronickel facility in the Dominican Republic which produces about 60 million pounds per year of contained nickel. In 1986, Falconbridge acquired Kidd Creek Mines Ltd. (discussed separately below).

In recent years, Falconbridge has started treating custom materials at its Norwegian refinery, and has recently signed a long-term contract with BCL of Botswana for the supply of approximately 35 million lbs. per year of nickel until the year 2000. Falcnbridge also has interests in a variety of other base and precious metal mines. Nickel provides approximately half of its corporate revenues, but since 1982 has been the major source of profits for the corporation. This will change significantly, with the Kidd Creek acquisition.

Until 1984 Falconbridge was controlled by Superior Oil Limited. In 1984, Superior was bought by Mobil Oil. In early 1985 Dome Mines bought control of Falconbridge from Mobil Oil, and in 1986 CDC acquired a significant interest.

Table 32

FALCONBRIDGE LIMITED FINANCIAL DATA 1980-84
($ million Canadian)

	1980	1981	1982	1983	1984	1985
Revenues	758	713	483	615	733	890
Earnings (loss)[a]	75	1	(82)	(31)	29	39
R&D expenditures	6.6	11.1	5.8	3.4	3.2	4.6
Total assets	1,231	1,335	1,165	1,263	1,165	1,351
Long-term debt/equity	0.59	0.95	0.89	0.91	0.45	0.36

Source: Falconbridge Limited, Annual Report, 1984, 1985.

[a] Before extraordinary items.

Research Organizations

Falconbridge cut back its research expenditures from $11.1 million in 1981 to $3.2 million in 1984 and $4.6 million in 1985. The Metallurgical Laboratory in Richmond Hill was closed, and some staff were merged with

the Metallurgical Process Technology Department in Sudbury to form the Metallurgy Technology Centre. The move was a cost-cutting measure as well as an attempt to link scientific and operating aspects more closely. Falconbridge is also a member of HDRK.

Research Interests

- mining - safety and productivity emphasis - e.g.:
  - ground control and rock burst studies
  - backfill, drill-rod automation, review of equipment strengths and weaknesses, improved ore recovery from pillars
  - automated down the hole drilling
  - evaluation of high-pressure water drills
- in processing and metallurgy - improved working conditions and metal recoveries, reduced costs, and new applications e.g.:
  - reduced metal losses during milling and smelting, and increased recoveries of nickel, copper, and cobalt

Denison Mines Ltd.

Denison is primarily an energy company, with uranium mines in Ontario, potash in New Brunswick, and coal in B.C., and uranium and oil and gas interests abroad.

Table 33

DENISON FINANCIAL DATA
($ million)

	Mining Only			Consolidated Financial Data		
	1983	1984	1985	1983	1984	1985
Revenue	259	246	246	676	703	737
Operating profit or net earnings	78	69	63	93	64	(158)
R&D expenditures	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total assets				1,745	1,965	1,724
Long-term debt/equity				0.3	0.3	0.37

Source: 1985 Annual Report
[1] Mining includes mining, milling and sale of uranium oxide, plus coal, potash, uranium, and other minerals.
n.a. = not available in annual report.

Research Organization

- Uranium research at Elliot Lake, as part of mining and milling operations.

Research Interests

- Mining
  - large scale underground testing of uranium heap leaching
  - backfill and drainage studies
  - up-hole drilling jumbos
  - low-profile mining equipment

Denison received a $1.6 million 2-year grant from the National Research Council in support of its bioleaching studies.

Sherritt Gordon

Table 34

SHERRITT GORDON FINANCIAL DATA
($ million)

	1980	1981	1982	1983	1984	1985
Revenue	360	327	275	337	397	445
Earnings[a]	28	2.8	2.3	4.8	(8.6)	(14.6)
R&D expenditures	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Current assets	149	176	133	130	164	203
Total assets	309	421	601	643	673	651
Long-term debt/equity	n.a.	0.30	1.21	0.91	0.92	1.03

Source: Financial Post Business Information Service.

[a] before extraordinary items.
n.a. = not available in source cited.

Research Interests

(Number of research personnel as % of total employees: 1983 - 4.9, 1984 - 4.8)

- Processing - optimization studies are the principal area of research interest for Sherritt Gordon.

- specific application of pressure hydrometallurgy for improved gold recovery from refractory ores
- Mining - studies are planned for productivity improvement
- New product development
  - metallic additives to plastics and paints to enable then to conduct electricity for applications in high-tech electronic equipment
  - composite powders
  - composite materials
- Technology licensing
  - successfully marketed metallurgical processes for many years, in nickel, copper, zinc, gold and platinum group metals alloys and composite materials - e.g. 2-17 cobalt, samarium magnet, and NBS and other new coinage materials

Cominco Limited

Cominco is a major integrated multinational firm, one of the Canadian Pacific group of companies until 1986, when it was purchased by a group headed by Teck Corporation. It is one of the world's largest mining, smelting and refining enterprises and producers of lead and zinc. Other mineral products include silver, gold, copper, tin, cadmium, bismuth, indium, diamonds, coal, steel products, fabricated metals, and high purity metals, compound semi-conductors and components for electronics and other high technology industries. Cominco is also a major producer of fertilizers and chemicals.

Table 35

COMINCO FINANCIAL DATA
($ million)

	1980	1981	1982	1983	1984	1985
Revenue	1,443	1,417	1,235	1,379	1,581	1,458
Net earnings (loss)	171	70	(31)	39	24	(97)
R&D expenditures[a]	n.a.	n.a.	n.a.	5.4	5.5	3.5
Total assets	n.a.	n.a.	n.a.	n.a.	2,100	2,056
Long-term debt/equity	0.43	0.67	0.83	0.75	0.70	0.87

Source: Financial Post Business Information Service.

[a] Operating budgets of the Technical Research Centre and the Product Research Centre
n.a. = not available in source cited.

Research Organization and Interests

- Mining and beneficiation - Sullivan Mine, B.C.
  - concentration operation and control
  - testing of in-the-hole up-hole drilling systems
  - underground communications and terminals
  - explosives
  - fire resistant hydraulic fluids
  - diesel emissions
  - permafrost stabilization
  - mining machine for hardrock heading dipping from +50° to +85°
- Beneficiation and metallurgy - Technical Research Centre, Trail, B.C.
  (1984 budget 3.2 million, staff 46)
  - gold heap leaching
  - improved purification of electrolyle solutions for zinc
  - new germanium recovery plant
  - new rotary furnace for tin-indium, and for silver production
  - improved processing of antimony and arsenic
  - recovery of soda ash from complex salt deposit
  - niobium recovery
- Processing - Trail Operations Development (staff of 48)
  - process improvements for zinc and lead
- Customer support - Product Research Centre, Sheridan Park, Ontario
  - applications of new technology for lead and zinc products
  - R&D on lead batteries
  - galvanizing
  - zinc alloy castings
  - continuous casting of zinc aluminum alloys for hearings
  - super plastic zinc forming (has been licensed to another company for development)
- New Materials - Electronic Materials Development, Trail, B.C. and Spokane, Washington (staff of 28, operating budget $2 million - emphasis on purity and quality)
  - high value-added germanium applications
  - thin-film cadmium mercury telluride infrared detector materials
  - gallium arsenide for high-speed communications and super computers
  - automated production equipment
  - high speed continuous casting for superior grade solder alloys

Kidd Creek Limited

Kidd Creek Mines has been Canadian-owned since 1981, initially by the Canada Development Corporation and since early 1986 by Falconbridge Ltd. The company operates a silver-copper-lead-zinc-cadmium-tin mine and a gold mine at its Timmins property, as well as a metallurgical site with copper and zinc smelters and refineries. It also holds an interest in a potash mine.

Table 36

KIDD CREEK FINANCIAL DATA
($ millions)

	1983	1984
Revenues	484	543
Earnings (loss)	(1.2)	16.9
R&D expenditures	n.a.	n.a.

Source: Kidd Creek Annual Report 1985

Research Organization

Kidd Creek's research activity facilities have in the past been integrated into operations, in both a physical and a management sense. A separate metallurgical R&D facility was established late in 1985. The technical programs were still in the process of being put together by management at the time of the takeover in 1986.

Research Interests

Research efforts in 1984 were primarily directed to productivity improvement and cost reductions in all operations: e.g.

Mine

- ore grade control
- energy conservation
- equipment modification - especially of drills
- backfill cost reduction

Metallurgical Site

- increased throughput
- improved recoveries
- cost reduction

HDRK Mining Research Limited

HDRK is an anomally in this section. It is not a producing company, but rather is a joint venture established in 1984 by Inco, Noranda, Kidd Creek, and Falconbridge to conduct R&D on strategic innovations of mutual interest. The annual budget for HDRK is $1 million, and its objective is to generate "quantum" improvements in hardrock mining productivity through the development of a continuous-type mining system.

HDRK has no research facilities of its own, but contracts work out to other technical organizations, including, but not limited to, the joint venture partners. Although some of its projects are still in the planning stage, its research interests include:

- development of technologies, techniques and equipment for cutting of hardrock with high pressure water jets and associated equipment and materials;
- improved productivity in raise boring;
- for the long term, various studies of continuous mining methods, including the use of ore sorters in conjunction with the continuous breaking of rock.

MIROC

The Mining Industry Research Organization (MIROC) is also a joint venture of a group of Canadian mining companies, created in the 1970s to conduct cooperative R&D. Among MIROC's projects are:

- improvement of miner's personal working gear, with respect to hearing, respiratory protection, and lighting equipment, including development of an air-flow helmet, a halogen cap lamp, a miner's worksuit, and a protective workbook;
- development of a monitoring system for mine ventilation;
- development of a new concept for underground radio communication;
- development of an underground system for air-powered space lighting.

Chapter 4. EMERGING TECHNOLOGIES

INTRODUCTION

This chapter gives overviews of the technologies identified by MOSST in commissioning this study as being of particular interest, first because they are new or evolving rapidly and therefore may offer special opportunities, and second, because they may be of interest across all the resource sectors, not just for minerals alone. By encouraging technologies that can be applied to two or more sectors, it is assumed, government programs can have more overall impact, a bigger "bang for the buck". The emphasis given in this chapter may lead to some seeming anomalies in the treatment of technology for the mineral sector, since some of the emerging technologies are still in the very earliest stages of application to mineral production.

Since the methods and equipment of mining (particularly underground hard rock mining) and of metallurgy have little in common with the other resource sectors, these emerging technologies are still for the most part peripheral to the major technology interests of mining. The core of mining operations is breaking and moving ore. Metallurgy applies chemical and physical processes to isolate and purify desirable metals. The equipment and methods required have little application beyond the mineral industry. Most commonalities arise in support systems such as computing and information technologies, or equipment enhancement such as remote control and robotics, or miniaturization. Biotechnology has long-term potential, but seems to be somewhat isolated both within biology studies (only one microorganism is presently of major interest to the mineral industry) and within mineral industry research, because it is widely seen as a high-risk long-term field of low R&D priority. Exploration has major areas of overlap with other resource sectors, since geosciences are important in the oil and gas sector, and remote sensing (a minor but growing interest for the mineral sector) is becoming important in forestry and agricultural applications, as well as in northern transportation.

The categorization of technologies here is somewhat random: biotechnology, for example, is based on the academic descipline from which it arises; others, such as information technology, refer to the purpose or service provided; and still others, such as robotics, refer to the resulting hardware.

Organization of the categories within this chapter is also inconsistent, in that some natural groupings or associations have been ignored. For example, biotechnology is treated alone, although it is logically part

of processing technology and could be integrated in chapters 8 or 9. Remote sensing information is part of geoscience, but nevertheless is included here under the heading of information technology rather than in chapter 5 on exploration. Equipment innovation includes a broad range of categories, some of which have been split off for separate consideration, such as remote control and robotics.

BIOTECHNOLOGY

Introduction

Biotechnology is the exploitation in industrial processes of the ability of certain biological agents to transform raw materials into desirable end use products. Growing understanding of the biological and chemical mechanisms involved have permitted the development of modern biotechnology, in which these agents can be controlled and directed to increase reaction rates, improve selectivity, and increase the volume of desirable products.

Biotechnological processes have been used for centuries in a wide variety of resource-related applications. The newly-acquired understanding of and ability to control these processes provides the potential to improve existing applications and develop new ones. Among the areas receiving attention in biotechnology research are energy production, chemical feedstocks, medical and pharmaceutical products, food products, environmental protection and management, and mineral recovery. The following section looks at existing applications and areas of potential in the latter field: mineral recovery.

Biometallurgy

Biometallurgy, or biohydrometallurgy, should not be confused with conventional hydrometallurgy or leaching processes which use chemical reagents to separate metals from their concentrates or ores. Biometallurgy is distinguished by the fact that the active agent in the process is a living micro-organism.

Many of the minerals mined in Canada, and worldwide, are found in sulphide ores. A group of micro-organisms, principally thiobacillus ferrooxidans, promote the dissolution of sulphide ores, which are normally insoluble, freeing the contained metals for recovery. These bacteria occur naturally in the acidic waters found in mines and waste dumps. Their action has been utilized to recover metals, chiefly copper, that

were not recovered in the beneficiation process and ended up in tailings piles. The run-off water from these tailings dumps contains significant quantities of recoverable metal. Rio Tinto's copper mine in Spain has made use of this natural process for centuries. In the United States, over 10 percent of copper produced in 1982 came from this source. More recently, as many U.S. copper mines and conventional extraction and processing facilities have closed down, the figure has risen as high as 100 percent for some mines in Arizona and New Mexico.

Over recent decades, the bacteria responsible for this process have been identified, and much has been learned about the local variations and strains, and about the effect of changing parameters on their activity. The bacteria are oxidizing agents, requiring abundant oxygen (as CO_2), specific nutrients, a highly acidic solution, and an ambient temperature of about 10-22°C. Their activity is affected by the constituents of the ore, particle size and porosity, circulation of air, temperature, and pressure. Rates of reaction increase exponentially with temperature. They can also be increased by changes in pressure, acidity, flow-rate, etc. For example, it has been found that the rate doubles for every 6°C increase, up to about 40°C, which is approaching the upper limit that can be tolerated by known strains of the bacteria.

There are other limits to increasing the reaction rate. The principal constraint is the fact that the products of the reaction will eventually poison the bacteria. Some dissolved metals, such as uranium, cadmium, and other heavy metals, are toxic to most strains of the bacteria even in fairly small concentrations.

Other active biological agents which can be used to separate metals include other strains of bacteria, as well as fungi and algae.

Innovation in biotechnology will require research in biology, genetic engineering, chemistry, mineralogy and extractive metallurgy. While mining companies are, and will continue to be, involved in ad hoc demonstration approaches to improving recovery rates through biotechnology, only an integrated and interdisciplinary approach can provide the kind of basic information needed to optimize these processes in a systematic manner.

Among the improvements looked for are increased reaction rates, improved selectivity for specific metals, resistance to poisoning, improved performance at low temperatures, and improved tolerance to high temperatures. With these improvements, biotechnology can provide both cost reductions over conventional beneficiation processes and revenue increases through the transformation of waste rock into recoverable reserves. Generally, it is believed that bioleaching will be most useful for treating tailings and ores that would otherwise be discarded because of their low grade, refractory nature, or other characteristics that make conventional treatment uneconomic.

Potential Applications

Treatment of Tailings

Natural bioleaching of tailings dumps, although inexpensive to exploit, is a very slow process, with low recovery rates, varying from 5 to 40 percent contained of metals over periods of 5 to 20 years. The introduction of relatively simple engineering and chemical techniques has led to significant improvement in some trials, and the techniques are beginning to be pursued more seriously. For example, the Toromocho mine in Peru designed and developed an optimized leach system which raised recovery rates to over 80 percent over a period of less than 3 years.

Optimization of tailings dump leaching will in most cases require either the creation of new dumps or the moving of old ones, in order to install facilities such as pads, draining systems, sprinklers, ventilation, temperature control, etc. Slow improvements can be expected in the treatment of existing tailings piles. For new dumps, however, the capital cost of improving recoveries will be relatively small. There is particular interest in Canada in improving recovery of gold and other high-value by-product metals in this way. Severe weather conditions in Canada are a major obstacle to high yields although progress is being made in this area.

The major study under way in this application is in Chile, where the IMF has funded a $200-million project expected to produce 50,000 tonnes of copper per year, at 35¢ a pound.

Overburden and Marginal Ore

In open-pit mines, the overburden may contain small amounts of the mineral in the underlying deposit. In both open-pit and underground mines, marginal ore or ore below the cut-off grade for conventional processing is rejected in the course of development and extraction. If the degree of fragmentation is adequate, these materials could be subjected to a dump leaching process which would, for relatively small cost, recover contained metal which would otherwise be lost.

Low Grade and Refractory Ore

Ore that is too low in grade or too complex to handle in conventional circuits is bypassed in the mining sequence of existing mines. It would be

possible to mine these ores, divert them to a dump, and use biotechnology to recover metals that would otherwise be left in the ground. This application could extend the reserves of old mines, or permit development of some new mines or new sections of existing mines that would otherwise be uneconomic. With complex ores, the leaching process offers the potential for additional recovery of byproduct metals as well, since these are often lost in conventional processing.

Research in the treatment of low grade and refractory ores has concentrated mainly on gold-bearing sulphides. A leader in this field is P.M. Mineral Leaching Technologies in B.C., which has recently concluded a joint-venture agreement with Texasgulf Minerals for pursuing the technology in Canada and the United States. A second Canadian effort in this field is the purchase by Taywin Resources, listed in Vancouver, of Biogold Research which is developing specific strains of bacteria for a variety of refractory ores.

In order to maximize control over the bacteria and the operating parameters, work is proceeding on tank or vat leaching, in which the concentrate is contained in a vessel, and bioleached in a batch or preferably in a continuous process. Equity Silver Mines for example has studied the feasibility of continuous vat bioxidation at its B.C. mine, and Grant Bay Resources plans to construct a $1.2-million mobile bioleach demonstration tank for highly refractory sulphide ores.

In-situ Mining

One of the main objectives in the search for new mining technology is the elimination of the drill-blast-haul discontinuous cycle of activities, and replacement of it by a continuous mining process. Bioleaching is one approach under consideration, but there seems to be agreement at present that the development costs for in-situ leaching of ore that is presently economic would be too high to justify the change, either in existing mines or in new mines. For example, a study by Noranda Research[1] concluded that the major drawback is the very high cost of development needed before leaching. Lower costs of fragmenting the ore in place are required to make the technology economically viable.

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1. A. Ismay, L. Rosato and D. McKinnon, "Engineering Feasibility for In-Place Bacterial Leaching of Copper", presented at International Symposium on Biohydrometallurgy, Vancouver, August 1985.

Denison Mines, with support from the federal IRAP program, is developing a bioleaching technology for in-situ recovery of uranium at its Elliot Lake facilities. The leaching process is now part of underground production, and is being tested for recovery of low-grade ore in mined-out areas. As in the Noranda study, Denison has found that fragmentation is a critical issue. Once the ore is broken in place, a flood/draw-off sequence is used to recover the uranium.

Internationally, pilot plant and large-scale in-situ bioleaching of ores is under development in a number of countries, including South Africa and Italy.

Refractory Concentrates

In general, bioleaching is expected to offer the greatest advantage if it can be used on low-grade ores before the beneficiation process. However, there are refractory ores of relatively good grades but of a complex nature which can be converted to concentrate form using conventional physical and chemical processes, but which then present difficulties for conventional approaches to extractive metallurgy. Chemical leaching processes such as cyanidation for gold concentrate and leaching of uranium concentrate are in wide commercial use already. Bacterial leaching is also expected to find wider application.

Biometallurgical treatment of concentrates would occur in closed systems, and could provide a number of advantages over energy-intensive and environmentally harmful smelting methods. For example, Warhurst suggests that "... metal recovery can take place on-site, in relatively small-scale solvent extraction-electrowinning facilities",[2] producing, for example, high-quality copper cathodes at considerably lower capital cost than a traditional smelting facility. It is also likely that bacterial action can be incorporated into such physical and chemical operations as flocculation and sedimentation, in order to improve recoveries in conventional beneficiation circuits.

Other Applications

Environmental protection is another area of interest in biotechnology in the mineral sector. The bacterial action in ore tailings and waste dumps is responsible for the acidic nature of waste water from mining operations. Understanding of the conditions that decrease reaction rates or poison the bacteria can contribute to control of acidity in such effluents.

2. A. Warhurst, "Biotechnology for Mining", in Development and Change, London, SAGE, volume 16, 1985, pp. 93-121.

Bacterial action can be utilized to remove cyanide and heavy metals from waste water. For example, Homestake Mining is using a biological method to remove cyanide after gold processing, and has encountered such high levels of gold and silver recovery that the plant is operating at a profit.

Bacterial action has been found to accelerate corrosion of metals in fresh and sea water, in soils, in pipelines, and other settings. Prevention or reduction of corrosion is therefore another area which will benefit from biotechnological research. Other areas of interest include coal cleaning and demethanation, degradation of concrete and paving materials, oil sands processing, and desilication of bauxite.

INFORMATION TECHNOLOGIES

Introduction

The information technologies discussed here are essentially computer based. The main components and aspects of computer-based information technology are:

- hardware - computing equipment and auxiliaries
- software - programs for utilizing the computers' capabilities in data handling, analysis, problem solving etc.
- expert systems - a subset of software, based on Artificial Intelligence concepts, designed to introduce expert advice plus reasoning into programs.
- communications - between individual computers, or computers and data bases, or computer networks.
- applications of particular interest to the mineral sector
    - information gathering
        - data bases
        - remote sensing
        - sensing (treated in later chapters)
    - data analysis and use
    - design - mine and process
    - automation and control

Hardware

Given the great range of companies included in the mineral sector, from the numerous small service companies and junior mining firms up to the

major integrated producers, cost considerations and skill requirements are important factors in determining what level of computing hardware, if any, mineral companies can presently employ. Although the distinctions between computer sizes are blurred, the following generalizations can be made.

Micros - $2,500 - $20,000 range. The smallest and simplest of the computer range, with capabilities that are being expanded daily through new software packages and communication links. They can stand alone, be linked to other micros, or be part of a network backed by a minicomputer or a mainframe. Their memory is in the 128-512 K range. They use floppy disks, and can can be backed up by hard disk.

Minicomputers - to a large extent, the low end of the mini lines are being taken over by micros.

Superminis - $50,000 - $500,000 range. These can support 30 to 40 active users, although heavy engineering demands might tax their capabilities. They have 2-8 megabytes of main memory, and up to a gigabyte of disk storage.

Mainframe - $250,000 and up into the millions. These can support very large user networks and heavy demands.

Auxiliary equipment - this covers a broad range of equipment to aid in computing, output, and communication, such as auxiliary memory drives, tape drives, printers, plotters, digitizers, modems, line drivers etc. Possible auxiliary equipment costs are included within the price ranges shown for computers above. Variations can be very large; printers, for example, can range in price from a few hundreds to many thousands. A good quality plotter can now be obtained for about $2,500.

A recent survey[3] of firms in the Canadian mineral sector turned up the following results from 198 respondents (information is not available on how the sample was selected). About 40 percent made no use of computers and another 28 percent had only one (divided as follows: 1 mainframe - 5.6 percent; 1 mini - 11.6 percent; 1 micro - 10.6 percent). Of

3. Cited in "Canadian Mining Industry", Vertical Market Profile No. 8501, International Data Corporation, Toronto, 30 July 1985.

those with computers, almost all had printers and 51 percent used plotters. For communications, most used dedicated lines but were not part of a network.

Software

As with hardware, the distinctions between kinds of software are blurred, but useful generalizations can be made.

Resident Software

This is resident in the computer (or microchip, in the case of automated equipment). It is preprogrammed to perform some specific action or actions, such as reading a program disk or converting from one language to another.

Applications Software

Most software fits into this category. Software programs can be purchased ready-made on disk or tape, and used as is or adapted for specific needs, or they can be programmed in-house or on contract for the specific needs of the user. They are used for virtually all computing applications; applications of specific interest in the mineral sector include data gathering and analysis for exploration programs, deposit evaluation and delineation, feasibility studies, mine design, process design, operations control in mining and processing, quality monitoring and control, environmental monitoring and control, market analysis and forecasting, and a host of other management and communication functions.

The International Data Corporation study found that the mining industry lags far behind other industrial sectors in terms of use of applications software in the areas of exploration, mining, and processing. The vast majority of mining companies using computers use them solely for administration.

Software has been developed for open pit mines (e.g. U.S. programs for Arizona copper mines; Queen's University, for open pit design.) CANMET has developed software (SPOC) to simulate some aspects of coal and ore processing. For underground mining, however, there are very few interactive software packages, i.e. programs that can be used for a continuous process of monitoring and decision-making for design, planning, and operations.

Virtually all of Canada's major mineral producers have developed software in-house, or purchased complete systems from computer services companies or consultants. Inco, for example, has developed programs for business, process control and design, including standard financial packages; programs for decision support systems for the mines, mills, smelters and refineries; both current and long-term scheduling; and several CAD (design) systems. Kidd Creek and Falconbridge have developed software in-house for a number of aspects of underground mining, including mine modelling, short-term and long-term mine planning, underground mine and stope design, and production database. Micro-computers have also been applied to underground microseismic monitoring systems. Campbell Red Lake Mine, Falconbridge and Hecla Mining have been working closely together since 1984 to develop systems for this application. Falconbridge now has microcomputer-based systems installed at all its mines in the Sudbury area.

The survey cited by IDC notes that, of the 298 programs identified by respondents, 53 percent were purchased, 16 percent were leased, 17 percent were used on a time-sharing basis, and 14 percent were used through a service bureau.

There is a need for an almost infinite range of new software configurations for the mineral sector, ranging from management systems through CAD (particularly for all sorts of underground mining) and CAPD, process and quality control software, environmental monitoring and control packages, and software for economic and market modelling.

There is also a growing market for services providing information on mining-related software, to familiarize companies, particularly smaller ones, with what programs are available and how such programs can improve their operations.[4] Companies in the mineral sector also need to upgrade the computing skills of existing employees or add staff with computing expertise, to ensure they are taking full advantage of computing capabilities in management, quality control, productivity, etc.

Expert Systems

Expert systems can be considered as a highly sophisticated subset of applications software. They are an offshoot of developments in artifical intelligence, fairly new, and relatively little used as yet. They operate much like having a consultant or firm of consultants at the disposal of the user, and can introduce information and advice that goes far beyond the usual capabilities of software programs.

4. One such service now available in the United States is the Directory of Mining Programs, listing over 420 computer programs designed for mining applications, available from Gibbs Associates.

An expert system package will provide a knowledge base, consisting of both specific facts and more general rules as the basis of a process of reasoning, plus an "inference engine", which explains its solutions. The potential for expert system applications in the mineral sector is very large. They can be applied in any area where software is now used, and are particularly suitable where both large volumes of data and judgement are required, as in deposit delineation, feasibility studies, mine and process design, and operations planning and management, as well as ground control and environmental monitoring and control.

There are serious constraints, however. Design of an expert system requires at least two experts: one in the subject matter, and one in programming. Conversion of lifetime experience, intuition, and "gut feelings" to machine language involves problems of communication. Furthermore, the cost of equipment, and the programming and engineering skills needed to take full advantage of an expert systems package, will be beyond the means of all but the larger firms for the medium term at least.

Development of expert systems is now proceeding in a few university departments of computing sciences in Canada. Industry is already showing interest. Alcan for example has expressed concern that its upper level of in-house expertise will be retiring in the near future, with the resulting loss of a great capital of knowledge and experience, and has begun to look at its own in-house expert systems. Incorporation of collective in-house expertise in a variety of expert system programs will help to preserve this asset for the company. This is a problem that must be faced by a great many mineral sector firms over the next few years, as cutbacks and hiring freezes have greatly reduced the proportion of younger employees and interfered with the passing of skills to a new generation.

Computer Communications

An almost endless variety of communication links between computers is possible. Most of the approaches to communication that might be of interest to the mineral sector are in general use, and in no way unique to mining. The exception is found in underground mining, which presents some complications.

Computer to Computer - Links and Networks

Computer terminals can access other computers including commercial and government data bases via networks using telephone links, which can be direct leased lines for frequent users; less-frequent users can dial into networks and pay only for the time used. Computers can be used for transmission of electronic mail, exchange of information, advice, and even software packages between individual terminals. Data base owners sell on-line services to computer owners, applying several modes of payment including subscription fees and/or fees for use, and by access time or by volume of information. In-house computer links can take the form of networks such as the packet switch system used by Canadian banks, but these are extremely costly and can only be justified by very large volumes of use. Most of those mining companies surveyed which used computer communications between facilities in different locations reported that they used dedicated lines. Other options include Bell's datapac system (dial a local number and be connected to a special line); or, a user can simply dial over regular telephone lines. Where companies or organizations are switching to digital phone lines rather than analog, modem links are no longer required for a digital-to analog conversion between computer and phone line.

Use of telephone lines to transmit data can lead to problems with static and noise which disrupt and distort the flow of information. Cominco, for example, found problems with telephone communications from its remote locations to its mainframe, and planned to put PCs at each remote site for some aspects of the support system.

Remote Locations

There is a growing interest in the use of microcomputers in remote locations in the field: for example, for logging drill core information at exploration sites. Transmission of the data from a portable terminal to head office can be made by finding a telephone or, in more remote locations, by flying disks or tapes out for delivery. It is also possible to transmit data by radio to a telephone link. However, the severe problems of noise and interference require fairly sophisticated software, with error detection capability at both ends. A second computer, probably a mini, and a modem, would be needed at the telephone connection. It is possible that a single unit, perhaps located in a DIAND office in the territories, for example, could receive safely coded or scrambled radio messages from a number of exploration field parties, and transmit them directly to the companies' exploration departments.

Some work is also under way in transmitting messages and data from remote locations in the Arctic by satellite. This technique could permit direct communication between field camp and head office, although the equipment and satellite transmission time is still quite costly. Advances have been made, however, in reducing the size and complexity of the transmitting equipment (it is now easily portable by small plane) and further work is in progress by the federal Department of Communications.

Open-Pit Mines

Computers are finding increasing applications in open-pit mining operations: for example, for scheduling of mining and trucking operations and monitoring of slope stability. Communications between data sources and computers in the pit to computers on the surface are handled, as in many similar operations such as large plants and construction sites, by line-of-sight low frequency radio transmission with a single transmitter at the surface linking all other units.

Underground Mines - Computer Communications

Underground metallic mines pose special communications problems, as a result of the metal-bearing ore, and the complexity and short lines of sight of the underground workings, with shafts, raises, levels, crosscuts, drifts, and stopes. Computers are beginning to appear in underground mines for management and technical functions, as well as ground and environmental monitoring. In order to take full advantage of the information that they can make available for management and operating decisions, it is important that they be linked directly to central computing facilities on the surface for data collection, analysis, and responses.

This in turn requires dealing with several problems, none of which are insurmountable:

i the large number and frequent changes of location of activity make it imperative to have a fairly flexible and mobile system;

ii line-of-sight radio links are of little use, given the complexity of the workings, so cables must be brought in along with other services and, in some cases, extended to areas not normally serviced;

iii underground equipment must be capable of surviving a hostile environment, wet and muddy and dusty, sometimes very warm or very cold, and subject to frequent concussion from explosions.

Data Bases

A data base is any collection of information, from a "little black book" of telephone numbers to, for example, the Statistics Canada CANSIM data base which provides computer access to many of Statistics Canada's data series. Data bases can be kept in a variety of physical forms, including printed sheets or lists; index or file cards; books, either bound or loose-leaf; or computer tapes or disk storage.

Accessibility to data bases varies as well. Some are private and confidential; some are private but available on a commercial basis; some are government owned and sold on a cost-recovery basis. Many have been developed by individuals or groups for their own purposes, but can be borrowed or purchased by others with similar needs if they learn of their existence.

The method of access may involve looking at primary files or cards, or receiving printed copies of records produced from hard copy or from data stored on computer. It may also be possible to buy computer disks or tapes, or to establish a direct computer link to move data from its home base to the computer of a user, who pays for this service.

The section that follows will concentrate on data bases where the information is stored on computer. Output may be in printed form, or it may be retrieved through a direct computer link or on tape in digital form.

Bibliographic Data Bases

Bibliographic data bases are computer-stored keyword indexes to printed material. References can be searched by author, date, subject, and other keywords. This is a rapidly growing and competitive field, served by a range of commercial and government agencies. Monthly magazines, such as On Line (U.S.) and On Line Review (U.K.), provide regular information on availability, cost, and means of access to services, lists of data bases and other aspects of on-line data bases. Further information is available from company newsletters, such as IBM's PC Week, or on-line through computer networks.

Canadian government agencies which provide access to bibliographic data bases include CAN/OLE and CAN/SDI, available through NRC, and the Alberta Research Council's on-line service. Commercial groups selling on-line bibliographic data base access (and in some cases full-text as well) in Canada include QL Systems, Info Globe, and Pergamon's Info Line. Major services in the United States are DIALOG and System Development Corporation in California, and Bibliographic Retrieval Services (BRS) in New York, and in the UK, Data Star. All these are accessible to individual computer users, with a variety of cost structures and charging systems, generally ranging from about $15 to $35 per hour.

Among the international bibliographic data basis of interest to the mineral industry are:

BGS MINsearch - geology, exploration, mining, processing, econmics, legislation
IEA Coal and Coal PRO - coal mining and processing publications
Georef - geoscience
CIS - occupational health and safety
ASI - U.S. statistics
Compendex - engineering
Dissertations abstracts - North American theses and dissertations
Energyline - energy
Metadex - metallurgy
World Aluminum Abstracts - aluminum metallurgy
Patsearch - U.S. patents since 1970

CANMET has developed several bibliographic data bases of specific interest to the mineral sector: MINTEC, with over 25,000 entries on mining technology from Canadian and foreign periodicals; and MINPROC, a similar listing for mineral processing and metallurgy. These are available on-line from QL Systems.

Literature or Full-Text Bases

Literature data bases: complete articles and published material can be sourced from these bases. There are few such services specifically geared to mining or mineral industry activities, although these and related keywords can be applied. Canadian examples of this type of service are QL Systems and Info Globe. QL systems, as noted, provides access to MINTEC and MINPROC.

Mineral Inventory Data Bases

The federal government and each province keep records of mineral occurrences and deposits, some of which have been listed on computer to assist in locating files of interest. Computer searches are done by the government agencies themselves rather than through direct computer tie-ins.

For example:

- The Geological Survey of Canada (GSC) produces GEOSCAN, a Canadian geoscience data base.
- MINSYS is a computerized index to the Canadian mineral occurrence records in the National Minerals Inventory kept by EMR.
- MINFILE provides computer-retrievable information on mineral occurrences in British Columbia.
- Ontario has several computer accessible data bases, including the Geoscience data index, the gold data base, the rock chemical data base (PETROCH), and the Mineral Deposit Inventory data base.
- Alberta provides on-line search services for many publicly available data bases, and has its own provincial data base as well.

Numerical, Statistical, or Information Data Bases

Some computerized data bases containing factual, numerical and statistical information have been developed and used by government agencies, by commercial data services, in universities and other research organizations, and in-house by companies for their own use. A few are widely advertized and distributed on a commercial basis or on a cost recovery basis, others are shared by people with similar interests, and probably most are kept confidential.

A very broad source of Canadian statistical data is CANSIM, which provides computer access to many Statistics Canada data series, including financial and production data on the mineral industry (aggregated to prevent identification of individual companies). The Canada Centre for Remote Sensing provides the Landsat data products, with information in the form of images or digital tapes. Four commercial suppliers and several provincial agencies offer image analysis services to convert the satellite data to a form that can be integrated with other geoscience data.

The major numerical and information data base of use to the mineral industry is Minesearch, developed and marketed by the Metal Economics Group in Colorado. This is a "compiled" data base, drawing on a wide

range of sources which are analyzed and keyworded. Sources include company filings and press releases, over 50 media sources, government information (including the U.S. Bureau of Mines' "Mils" data base covering over 60,000 U.S. properties), as well as personal interviews. Information covers such activities as exploration, acquisitions, strategic planning, engineering, financing, equipment, and marketing.

Commercial on-line data bases of general interest include API Sharpe and Data Crown. However, most numerical data bases appear to have been collected by individuals or groups for their own purposes. Many are kept confidential because they include proprietary information on matters such as production costs, ore grades, smelter terms, price agreements, contracts, etc. In some cases, such confidential information has been assembled on a broad basis, and is made available, through application of suitable software, in the form of analysis where the published figures are aggregated or averaged to preserve the confidentiality.

Conclusion

In summary, it seems that considerable confusion remains in the area of data bases specifically for the mineral industry. There is no single encyclopedic source of information, such as an all-inclusive data base catalogue for potential users to turn to, although there is a rapid proliferation of partial directories of data bases and programs from government agencies and commercial organizations. Worse, there seems to be little general knowledge of the range of sources and services available, even among some government agencies in the data base business and researchers in the field. This complicates the task of the mineral industry user, particularly from smaller mineral firms with few resources, in trying to identify and gain access to these information sources.

Future developments in data bases may move away from bibliographic sources toward more full-text or encyclopaedic sources on-line.

Remote Sensing

In its broadest sense, remote sensing includes any method of reading information or measurements from a distance. It can include vibration measurements of equipment, observation of open-pit operations by on-site cameras or other sensing devices, airborne photographic and geophysical operations, and satellite programs. In each case, the information transmitted can be converted to digital form for computer-based analysis. In

this section, satellite remote sensing only will be considered. The satellite information, in the form of digital data, and used in combination with other geophysical, geochemical, geological and geobotanical data, greatly increases geological mapping and interpretation capability.

The first remote sensing satellite for civil land observation purposes was launched by the USA in 1971. ERTS-1, later renamed Landsat 1, was followed by Landsat 2 and 3. Interest in geological mapping and interpretation applications of the data from these satellites was slow to develop, in part because they were suitable primarily for agricultural, hydrological and land use planning purposes and in part because of what appears to be a resistance by the exploration industry to this new and untried technology.

A major breakthrough occurred in 1982, with the launching of Landsat 4, which combines the original Landsat multispectoral scanning (MSS) sensing system with the thematic mapper (TM) multispectral scanning device. For geological purposes, the addition of the TM system is a significant improvement, offering improved resolution (30 m vs. 78m) and new short wave infrared bands. The new bands add a capability for direct detection of mineral assemblages containing clay, carbonate, sulphate, and phosphate type minerals, while the MSS system primarily detects surface iron oxide variations. Landsat 4 greatly increased capability for more accurate mapping of minerals, rocks, soils, and geobotanical anomalies.[5] The high-resolution TM Landsat 5 was launched in March 1984, further improving the quality of information for geological interpretation. As of 1982, it was reported[6] that over 60 firms in the areas of energy, minerals, engineering and related services world-wide had developed their own in-house software to process Landsat data. In Canada, at least 4 companies offer analysis services on a commercial basis.

The French satellite, Spot, offers solid state (nonscanning) multiline array sensor data in the visible and near infrared region, similar to that from Landsat's MSS. It has a much higher level of resolution (20 m and 10 m) for greater detail, and a pointable stereoscopic capability, useful for topographic mapping. Other satellite systems planned include SLR radar, Radarsat, ERS-1, Jers-1 and experimental systems such as the U.S. Large Format Camera and the German Moms multispectral linear array sensor.

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5. Biogeophysical mapping techniques involve identification of metal-induced stress in vegetation, i.e. geobotanical anomalies.
6. Henderson, World Mining, March 1983, pp. 44-46.

The Canada Centre for Remote Sensing (CCRS) receives satellite data from the Landsat satellite and is building a receiver for Spot transmissions. CCRS is also developing its own satellite, Radarsat, which is expected to be launched in 1990. It will have applications for ice forecasting (essential for northern shipping), crop monitoring, oil spill detection, and resource exploration.[7] Radarsat will be equipped with synthetic aperture radar (SAR), capable of "seeing" under all weather and lighting conditions. Its stereo capability will enhance its usefulness for topographical mapping, and its sensors will be particularly useful for geobotanical applications.

Mineral Industry Applications

Remote sensing data can provide input into the basic geoscience information base upon which the exploration industry depends. This information base is usually provided by government geological surveys and mapping branches in the form of maps and reports, and is available to the general public. It also serves as input to the development of basic theories about geology and the formation of mineral deposits.

Exploration companies make use of the data base and geological theories to select regions and favourable areas for their exploration programs. The data can also be used by exploration companies, integrated with their own data, as part of their own programs.

With the exception of a few large companies such as Noranda and some exploration consultants, the exploration sector has paid relatively little attention to the Landsat data, although interest is growing. Data can be obtained in photographic form from the CCRS receiving station in Prince Albert, or it can be purchased on digital tape. Use of the tapes requires access to an Aries software system for analysis, interpretation, integration with other data, and conversion to graphic form. The Aries system is available from at least one Canadian firm, which offers its services on a commercial basis, and from the Ontario Centre for Remote Sensing. Noranda and possibly several other large firms also have the Aries system in-house. CCRS in Ottawa provides access to its Aries system and assistance in its use to scientific researchers, but not for exploration programs.

There is a need for wider knowledge of the existence and applications of the Landsat data; to this end, CCRS has advertised it in a number of general and sector-specific publications. There is a need for education of potential users in the techniques of interpretation and integra-

7. EMR, GEOS, Vol. 12, No. 1, winter 1983, p. 13.

tion with other data. Some work is done in this line by CCRS, but in general it has been left to the provincial agencies, particularly the remote sensing centres in Ontario and Alberta. It would seem that there is a role here for the Geological Survey of Canada and for university departments as well, in research and education in the techniques of data interpretation and the integration of remote sensing data with other geological, geophysical, geochemical, and geobotanical data.

Data Analysis and Use

In general, mineral industry firms' computer and software requirements are much the same as those of any sector. Standard software packages are available and easily adaptable to mineral industry applications for analysis and use of data. These include management programs, accounting spreadsheets, and various data file programs. They can be used for personnel management, production management, product inventory records, purchasing and supplies inventories, shipping, marketing and other operating and record-keeping purposes. For the mineral sector, as any other, the major advantage of computers in data analysis and use is the computer's capacity to handle and manipulate very large volumes of data quickly and with minimal input of person-hours.

Special applications that might be unique to the mineral sector include packages to integrate geoscience data (e.g. geochemical, geophysical, remote sensing, and other) in identification of interesting areas for ground follow-up exploration. Computer techniques are particularly appropriate to mineral exploration because they can combined the integration of large amounts of quantitative and qualitative information with the capacity to convert the results to graphic form, as diagrams, maps, cross sections, etc. The combination of geological data and geostatistical techniques for deposit and reserve delineation is another specialized area of data analysis, as is the interpretation of information on ground stability.

The application of computers in the mineral industry for data collection and analysis has been piecemeal, and has had a relatively small impact on techniques and capabilities. Among the constraints indentified are the lack of appropriate resources among the companies, the lack of computer technologies specifically for the sector, education problems, and attitudes within the industry.[8] A forum or centre for the exchange of in

8. M.F. Horder, "The Information Concept - An Integrated Approach to Computing in Mineral Exploration" Computer Applications in Mineral Exploration, Toronto, January, 1984.

formation on the availability and application of mining-specific software and standard programs adapted for mining and mineral-related purposes would be a valuable service, particularly for smaller firms without the capability for in-house programming. Such a centre could also become a central clearing house for storage and analysis of mineral industry data.

Computer-Aided Design

Computer aided design (CAD) is a rapidly growing field that goes far beyond the data storage and analysis functions referred to in the section above. At a minimum, CAD software can eliminate almost all drafting requirements, a major item in mine design and operation. At best, it can make major reductions in cost and time, and improve quality and flexibility in the design of new mines or extensions of existing operations. In the field of mine design, CAD applies engineering and economics concepts, methods, and formulae to the relevant data, in order to produce all the necessary calculations and drawings for the construction, development, and operation of a mine. The number of parameters, volume of data, and kinds of calculations required are extremely extensive, looking at three dimensions in space, as well as time and cost dimensions. Since each mineral deposit is unique, general-purpose software packages for mine design are very involved, and place heavy demands on programmers, operators, and equipment.

CAD offers a number of advantages to the field of mine design. As in exploration, large volumes of data can be manipulated, in this case adding engineering and economic techniques, and the results are produced in numerical, textual, and graphical form. Mine design requires the integration of information from geologists, mining engineering, and metallurgists throughout the design. This collaboration has frequently been insufficiently integrated, as a number of instances of difficulties arising from inadequate deposit information in recent mine developments will testify. In addition, there is a feeling that mining engineers as individuals tend to draw somewhat narrowly on their own experiences and personal knowledge in designing mines, and may ignore experience that is more relevant for the problems at hand. Some companies try to overcome this problem by deliberately looking for a cross-section of educational and work experience in their design teams. CAD would expand the sources of expertise further and in a less haphazard manner; the addition of expert systems, still far in the future, would provide an even more systematic base of knowledge.

As noted in the section on software, much work is needed on the development of generalized software for mine design. Open pit design has received the most attention to date. Queen's University's Department of Mining Engineering, for example, has developed a comprehensive design system for open pit mining. The system, which took over 5 person-years to develop, operates on a mainframe computer with a graphics workstation. It can be used for efficient and flexible design in a variety of real-world situations, and includes a deposit data base for use in teaching mine design.

Work in underground mine design has tended to be in-house and project specific, as for example at Kidd Creek and Inco. The Canada/Manitoba Mineral Development Agreement includes funding for development of an interactive computer graphics system for underground mines similar to that already developed for open-pit mines. The description of the project notes that the proposed CAD system will:

> increase the efficiency, accuracy and safety of mine design by allowing the designer to make corrections and changes in detail that are automatically incorporated into all other aspects of the design. The computer graphics system will remove the need for repeated redrafting of plans following changes, thus improving mine development schedules and lowering costs.[9]

Computer-aided process design (CAPD) offers the same advantage as mine design software in terms of volume of data, built-in engineering and economic capabilities, rapid handling of changes in design, and graphics. It can be applied to all of the processing phases of the industry, from beneficiation, through materials handling systems, extractive metallurgy processes, and production of various shapes, forms and materials. Work in this area is generally being carried on in a fragmented and ad hoc manner, in university departments in various disciplines, in industry, and in government facilities.

One exception to this scattered approach has been the development of SPOC, a program for the simulation of processing of ore and coal. Coordinated by CANMET, the SPOC program standardizes various computer-based methods for process evaluation and optimization. Cooperation with industry, government and university operators and researchers in the mineral and coal sectors provided input and feedback. CANMET officials see SPOC as a means of both integration of approaches and technology transfer from researchers to application in industry. They hope SPOC will be:

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9. Canada/Manitoba Mineral Development Agreement, Schedule A, p. 19.

a seed for a systematic integration of the new family of process evaluation and optimization which have largely remained in the academic and research publications.[10]

The survey of computer application in mining by H.A. Simmons Ltd.[11] indicated that respondents felt the need for CAD software development in a number of open-pit and underground design areas, including:

- optimization of short-term and long-term planning;
- dragline, truck, and shovel simulation;
- orebody modelling;
- comprehensive design system for underground mining and stope scheduling, in hardrock and for coal and potash as well.

Information Technology for Automation and Control

A major area of potential for technological impact on production costs and competitive position in the mineral sector is the automation and control of mining and processing activities. This will require supporting developments in a number of areas of technology, including continuous mining and processing techniques and equipment, robotics, sensing and feedback systems, and interactive software to control operations, including responding to changes in ore quality, operating conditions, and output requirements (see also pages 114-120).

The mineral industry has not utilized the capabilities of computers, sensors, data transmission, monitoring and control systems to automate its operators nearly as much some other sectors. To the present, the application of these features in underground mining has been for monitoring purposes only, or for control of specific operations in a nonreactive manner only. Some systems have been developed for scheduling of operations in open-pit mines. In processing, although simulation packages have been developed, the capabilities of information technology have generally been applied only to monitoring, rather than to automation of the processing and metallurgical circuits, in a few of the newest and most advanced facilities.

Among the potential applications for automation and control in underground mining are the following:[12]

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10. CANMET, SPOC: Simulated Processing of Ore and Coal, How to Get the Most Out of a Rock, Ottawa, October 1983.
11. H.A. Simmons (International) Ltd., Investigation of Computer Software and Hardware in Surface and Underground Mining in Canada, Final Report, CANMET, April 1985.
12. Patrick Whiteway, Northern Miner, 4 April 1985, p. B1.

- electronic monitoring of production activities such as flow of ore in an ore pass, and evaluation in terms of the production plan;
- monitoring and daily summarizing of all mine operating parameters, and integration of this information with production data;
- introduction of variable-speed drives and programmable controllers for equipment that would react automatically and reduce energy and maintenance costs;
- replacement of hydraulic controls with electronic controls on drill jumbos;
- monitoring of vehicle performance to establish maintenance schedules;
- monitoring of emissions to control ventilation systems.

Application in process and metallurgical circuits are also numerous. For example, monitoring and response could enhance efficiency and product quality in physical separation of waste and ore, in all phases of pyro- or hydrometallurgical extractive processes, in refining, and in product forming. The necessary sensing technology in most cases is already in use in other sectors and other processing operations, and but it needs adaptation to mineral industry use, plus the development of appropriate software to evaluate and respond to the information received.

Development of control technology for automation of mining and processing activities will require close collaboration of mining and processing personnel with the designers, manufacturers and suppliers of sensing equipment and control software and hardware. Assistance from applied researchers and exchange of information and experience will facilitate the implementation of control technology.

Person-to-Person Communications - Underground Mines

This is an aspect of information technology that is not computer-based, but is important for efficiency and improved productivity in underground mining. Mining crews work as individuals or in small groups in widely scattered work points throughout an underground mine, and most of the workers are quite mobile, moving from one location to another throughout each shift. Quick response to equipment, ground control, environmental or other problems is possible only with constant, direct, person-to-person communication links between each worker, the maintenance and supervisory staff, and surface management. Furthermore, for health and safety reasons, it is possible that legislation may eventually be passed requiring each employee to carry a communication unit. Only a few of the larger operations are now beginning to acquire this capability.

Kidd Creek, for example, has purchased the Silec system which was developed in France, and is adapting it for use in their Timmins operations. This system uses existing media, such as water or air lines or power cables. A radio signal is carried on the surface of the media, which must be insulated where it comes into contact with door frames on other possible conductors. Unlike some other systems in use elsewhere, it does not require frequent boosters along the lines. Call stations are placed at convenient locations along the system. Some individuals also carry portable units which can operate at 15 to 20 feet from the carrying media. The portable units are still somewhat cumbersome, and require recharging after every shift. The system is vulnerable to blasts and bumps in the mine.

Falconbridge, following a study of the state of art in underground communications, is testing an Austrian system in its Lockerby Mine.

Other systems are also available for underground use, although none are yet considered ideal or universal in application. Work continues in adapting existing systems and in developing new systems for Canadian conditions, including, for example, a project in the technology component of the Canada-Manitoba Mineral Development Agreement.

REMOTE CONTROL, ROBOTICS, AND AUTOMATION

Introduction

Robotics is one aspect of a continuum of applications of high technology toward enhancing the productivity of labour. The continuum begins with simple machines, such as fork lifts or jackleg drills, which increase workers' physical strength. More sophisticated machines such as load-haul-dump (LHD) trucks and drill jumbos are found further along, as are mechanically operated manipulating devices. It is also possible, adding microelectronics capabilities, to build sensing and response capabilities into equipment to assist the operator. The next step is to remove the operator from the equipment, and let him operate it from a distance but still within his line of sight, as is done with remote scooptrams. Beyond the line of sight, operator control can be maintained with the help of sensing devices, such as cameras. Robots can be programmed with increasing levels of independence from operator control, for simple repetitive tasks, or for combining monitoring and response capability with programmable logic for greater performance flexibility. Linking of robots and/or control devices performing a succession of tasks leads to process automation.

The three major sections of this continuum - remote control, robotics, and automation - have a number of features in common: all require input of information, through human senses and/or through sensing devices, and feedback through operator response and/or software designed for the purpose. Simple remote control generally involves only a human operator for information and responses. Manipulators and telemanipulators similarly rely on operator control, but provide increased safety, strength, etc. A robot can combine operator input with programmable response capability. Without operator feedback, simple robots can have fixed sequence programs, or limited flexibility through servo-mechanisms that respond to sensors. The more sophisticated robots are defined as "reprogrammable multifunctional manipulators designed to move materials, parts, or tools through variable programmed motions for the performance of a variety of tasks". Automation is the intelligent control of an entire process or series of processes, through the integration of a variety of sensing, analysis, and response operations that are optimized and controlled by computer.

Application of these technologies can offer a number of advantages to the mineral industry. For example:

- increased efficiency in many of the tasks in mining requiring considerable physical strength, which can be provided by remotely controlled equipment and manipulation robots;
- increased safety, by removing operators from unsafe areas;
- improved quality of product, since output should be more consistent;
- improved working conditions - safer, less physically demanding;
- less social disruption following cut backs and closures (once reduced workforce levels have been established);
- greater flexibility in production processes (when using reprogrammable robots, rather than continuous process control).

An advantage of robots that is always promoted in manufacturing applications is productivity improvement, since far more product can be produced per worker. However, this is not an objective in mining, since the markets for most metals cannot absorb production increases, under present conditions. Productivity improvement in mining is usually measured only in terms of reduced unit costs of production, without improvements in the economies of scale that are available to most sectors. Generally, therefore, productivity improvements in mining are tied to workforce reductions.

In 1983, Noranda commissioned a study of potential applications for robots in mining, smelting and refining. The consultants' report indica-

ted that the state of development of robotics technology precluded any applications in the near future; the nature of the tasks and operating conditions were found to be unsuitable for robot applications. A few potential applications were identified in smelting and refining in repetitive application, although the reliability of the equipment may be affected by the harsh operating environment existing in most facilities.

Present Applications in the Mineral Industry

In spite of initial pessimism, remote control is now seeing increased application in the mining and mineral processing industry, particularly for hazardous tasks such as ground preparation, scooptram operation at draw points, or where radiation is a problem. A remotely controlled automatic screener and rockbolter has been developed by Spar and Inco, and carrousels for drill rods are in use in some Canadian mines. Work is in progress on automatic drilling techniques, although practical applications are limited to a few larger mines at the present time.

Robots per se are at present not in use in underground hardrock mining, although they have found application in some processing operations, such as for acid dipping or repetitive hammering and pick-and-put tasks. Full automation and continuous processes in mining and mineral processing likewise are still goals for the future. Unfortunately, there appears to be relatively little R&D in robotics in mining or processing in Canada. For example, CANMET's mineral data bases report only 22 publications keyworded to robotics since 1975. There is a recent increase, however, since 16 of the 22 robotics entries occur in the 1983-85 MINTEC listings. Far more work has been reported in automation, with 905 entries in MINTEC and 596 in MINPROC since 1975.

Significant progress towards automation has been made in underground coal mining, where deposit configuration and relative softness of the coal make it particularly amenable to continuous mining methods such as the tunnel-boring machine. For hardrock mining, techniques for replacing the drill-blast-muck cycle with a continuous process of rock breaking, fragmentation and removal are under investigation in a few mines and research centres. Some attention is also being paid to the addition of microprocessor or computer control for several aspects of mining, such as drilling, ore handling, backfilling, and ventilation. Small advances in this direction are being made by some companies on site as part of normal company operations. In a very few cases, research and development attention is being focused on these areas in a systematic way. Inco, for example, has commissioned a California firm to develop a

robot vehicle for underground mine development and ore handling, and hopes eventually to manufacture and market the vehicles. Delivery is expected early in 1987.

In mineral processing, more progress has been made toward automation and control, although much remains to be done. In most cases, mills and process facilities described as automated or controlled are in fact controlled in pre-set patterns, or by operator response to monitoring information. For example, Westmin's new mill at Campbell River, one of the newest mills to come on stream in Canada, has been described as "almost totally automated".[13] Although the system has a 17-stream on-stream analyzer which monitors operations, it is not yet tied into process control. Many of Canada's older small mills, with operating staffs of 2 or 3, have no incentive to introduce automation, although larger ones are adding monitoring and analyzing capabilities in gradual moves in that direction.

Several Ontario mining companies pursuing R&D in the field of remote control and automation have enlisted the help of the Ontario Centre for Microelectronics and the Ontario Centre for Resource Machinery, both funded by the Ontario government. CANMET has supported studies and communication in this area through commissioned studies, a workshop and proceedings,[14] R&D contracts with industry for development of prototypes, and in-house work on monitoring and control systems. A recent initiative in this direction is establishment of CIM's Ad Hoc Committee on Robotics and Automation, which held its first symposium in Sudbury in the fall of 1986.

Potential Applications

Exploration

Information technology will be the major application for automation in mineral exploration. In the area of microelectronic control, down-the-hole drilling is of considerable interest, because this technology will permit greater accuracy in locating and controlling the drill bit, and will provide more information about the conditions encountered.

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13. Northern Miner, September 30, 1985.
14. P.R. Mainwaring and J.A. Potworowski, editors, Robotics and Automation in the Mineral Industry, CANMET, 1984.

Mining

Remote control and robotics will see increasing applications in mining, for two major purposes; worker health and safety; and reduction of labour costs. This trend will be encouraged by several factors:

- very high grades in new underground uranium deposits;
- increasing concern about health and safety issues in general;
- increasing depth of existing underground mines, and related problems of ventilation and travel-time for crews;
- increasing proportion of underground mines, as surface deposits are exhausted;
- increasing interest in ocean mining;
- the need to reduce unit costs of production.

Automation and process control in mining will likely be limited to specific tasks rather than total operations control over the medium term, such as scheduling of ore movements in both underground and open pit mines, or underground ventilation.

Among the tasks that have been identified as likely candidates for wider use of remote control and robotics in mining are:

- drilling, drill rods, sequencing, guidance, location;
- explosives handling, including unspent charges;
- ore handling, by truck, train, conveyor;
- ground conditioning, e.g. scaling, rockbolting, shotcreting, backfilling;
- mining in dangerous areas, e.g. draw points, pillars, ocean mining.

Milling, Smelting and Refining

These three stages in the mineral production cycle lend themselves more readily to process control than does mining, because the activities occur in permanent sites, with relatively constant ambient conditions and fairly predictable feedstock and products. Beneficiation of ore requires a very wide range of physical and chemical processes, including: preconcentration by mechanical sorting; comminution (size reduction); separation by size, density, and magnetic properties; separation by cyclones; screening; flotation and flocculation; and thickening and drying. Given suitable sensors and instrumentation for on-line measurement of process variables, truly automatic process control for all aspects of any particular mill or mill circuit is a possibility.

Smelting and refining processes in newer plants are further advanced towards automation than milling. This is partly because these facilities are much fewer in number than mills, with much higher capital cost requirements and very competitive operating conditions. In addition, the quality control requirements have contributed to development work on sensors for monitoring of process streams, sensors that are required for process control as well. Future applications will see improved sensing and monitoring devices for continuous monitoring of all constituents and conditions of the process streams (no mean feat in smelting and refining, given the complexity of many of the concentrates and the high temperatures involved), as well as development of software for analysis of the information obtained and control of the process. During the transition to automation in mills and pyrometallurgical processes, there will be an increasing use of robotics and remote control, in part to relieve workers of dangerous tasks, and in part to facilitate eventual automation.

Hydrometallurgical and biometallurgical processes, which are more akin to traditional chemical processes, will lend themselves to automation and process control more readily than most aspects of the industry.

Requirements for Technological Innovation in Robotics and Control

Task Evaluation

It would be a waste of resources to design robots and remote control equipment simply to reproduce the tasks presently performed by employees and existing machinery. While in the short term it will be practical to automate existing equipment, for the long term, activities must be evaluated in basic terms to see if a better approach, for example to rock breaking, or crushing, or moving the ore, can be devised. This basic research will be particularly necessary in the processing stages, which are still largely a mystery in terms of understanding of the chemical mechanisms and physical processes at work.

Sensors

Much work still needs to be done in adapting existing sensing devices and developing new ones for the very varied requirements and rugged operating conditions encountered in mining and metallurgical processes. A tremendous amount of information is already being collected in some mines, mills, and smelters - far more than the industry knows how to use

at present. Once it acquires an improved understanding of the many processes involved, the industry will be better equipped to identify the kind of information it needs to monitor process streams and quality, and to control them, either by operator or automatically.

Toughening

Sensors, communication devices, microelectronic equipment, robotics, computer terminals and other high tech equipment must be extremely durable to survive the difficult operating conditions encountered, particularly in underground mining, in mills, and in pyrometallurgical facilities. In underground mining, a high degree of reliability is required, because of the great distances often found between production areas and maintenance shops or staff, the safety problems that may arise in case of equipment failure, and the interdependence of all the activities underground.

Software

Development of software for data gathering, analysis, interpretation, programming of equipment, and control of processes is an area of major importance that will require collaboration of technical experts from the mineral industry with programming experts. It will also depend on the success with which the first requirement, task evaluation, is pursued, since a detailed knowledge of the physical and chemical and biological conditions, mechanisms, and processes involved are a necessary precondition to the software development.

Chapter 5. OPPORTUNITIES IN EXPLORATION

GOALS OF EXPLORATION

- understanding the basic geology of an area, region, country, etc.;
- understanding the fundamental processes of geological formation and change, and of the deposition of minerals;
- identifying areas of interest for mineral exploration;
- identifying mineral occurrences;
- identifying and evaluating ore deposits.

The first two goals involve basic geosciences and are absolutely essential to the last two, which are mineral exploration per se. The former are advanced through research in the public domain, mainly by government surveys and university geology departments. The third goal, identification of areas of interest, requires the collection and interpretation of large amounts of data, generally published as reports and maps. Government geological survey departments perform a major part of this activity in Canada, supplemented to a minor but increasing extent by private sector information gathering. The last two goals are generally pursued only in the private sector.

EXPLORATION ACTIVITIES

Development of Basic Theories

In Canada, this work is pursued mainly in universities and in government geological survey departments, particularly the Geological Survey of Canada. Development of new theories and new concepts may in some cases be translated very rapidly into new mineral discoveries and mines, although in many cases considerable time will pass before they can be fully appreciated and exploited. Examples of quick results include the response to new understanding of the formation of uranium deposits, which very soon led to discoveries of a number of high quality uranium deposits in the Athabasca region. Major advances in the understanding of ore genesis have resulted from the acceptance of such concepts as continental drift, sea-floor vulcanism, and sedimentary origin, as well as from improved understanding of the physics and chemistry of epithermal systems. The recent discovery by Canadian geologists of ocean-floor sulphide zones in the process of formation, for example, will help with find-

ing on-shore sulphide deposits of economic value; such geothermal systems are, in effect, modern analogues of epithermal systems.

Collection of Basic Geoscience Data: Surveys and Mapping

This activity in Canada has been conducted for the most part by federal and provincial geological survey departments. Beginning with surface surveying, and expanding (usually at the very forefront of the state of the art, particularly in the case of the GSC) into new techniques such as airborne reconnaissance and, more recently, remote sensing, Canada has probably the best geological data base of any country anywhere. Government survey information has been supplemented by privately collected information: for example, from assessment files and drill cores that are no longer confidential. It is all in the public domain, and made available in many varieties of maps and reports.

The private sector has becoming increasingly involved in this activity in recent years, as a growing number of companies offering services in airborne reconnaissance surveys have been hired by provincial and federal survey departments. A few firms have also begun supplying services related to interpretation and use of imagery from Landsat.

Technological innovations supporting ground surveys, airborne reconnaissance, and remote sensing have generally come from the private sector, although there are few significant examples of equipment that have originated within the GSC. The GSC has also been notable for its quick recognition and use of innovation in this area.

Many of the leading techniques in airborne sensing were developed in Canada. For example:

- airborne electromagnetic (AEM) systems, supported from 1946 on by a number of foreign-controlled firms including Inco, Hunting, Rio Tinto, Newmont (their system was used by Texasgulf to discover the Kidd Creek Deposit in 1958), and Selection Trust.
- airborne magnetometer, developed for the U.S. navy and brought to Canada by Gulf in 1946; GSC started using it the same year for systematic total field aeromagnetic coverage of all Canada, a project which was just completed recently.
- gamma-ray spectroscopy, conceived by professors at the University of Manitoba in 1948, but not in wide use until the uranium rush of the 1960s and 1970s.
- induced polarization (IP) - conceived at University of Toronto, 1946, developed with funding from Newmont Mining Corporation of New York, plus some NRC support.

It is interesting to note that, although 4 of the 5 innovations mentioned above were funded by U.S. or U.K. money, all were primarily Canadian in focus. According to Dr. Harold Seigel, president of Scintrex, the factors that made Canada an attractive location for these developments included: "favourable geology, a lenient fiscal policy, a stable free-enterprise government, receptiveness to foreign investment, and proximity to U.S. and European markets. ... The roles of the federal/provincial governments in the research accomplishments listed above may ... look very small, but in fact they were, indirectly, very important, for they provided the climate wherein the basic incentives could exist to explore for mines in Canada".[1]

Exploration Programs

These are conducted by a variety of companies, including Crown corporations, private and publicly-traded mining and junior exploration companies, and geological consultants, usually acting on behalf of a client. Generally speaking, the programs follow more or less the same sequence of activities, regardless of the nature of the company. In all cases, the information gathered is kept confidential until the ground area in question has been rejected as an interesting prospect by the company.

Exploration programs are sequential information-gathering activities, at each step looking at smaller and smaller areas in greater and greater detail. The steps include some or all of the following. The first 5 steps, up to the discovery of a mineral occurrence, are considered primary exploration, i.e. looking for signs of mineralization. Secondary exploration measures the extent of the mineralization found.

i Identification of region of interest. This is a desk job, drawing on the publicly-available geological data base, knowledge of geological theories, plus relevant market, political, economic, and other factors.

ii Area selection. Within the regions, (e.g. Ontario, or Quebec) an area of concentration will be selected (e.g. Hemlo, or Chibougamau). This is also mainly a desk job.

iii Reconnaissance. Usually involves airborne geophysical surveys to identify anomalies for ground follow-up study.

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1. Quoted in Research and Development Bulletin, Supply and Services Canada, September 1982.

iv Follow-up ground exploration. Requires linecutting, geological mapping, ground geophysical and geochemical surveys, and trenching. If successful it leads either to the discovery of a mineral occurrence, or to exploratory drilling.

v Exploratory drilling. When it is successful, exploratory drilling leads to the discovery of a mineral occurence or occurrences which, if sufficiently encouraging, will be followed by the secondary, or delineation, stage of exploration.

vi Delineation. The major activity of the secondary exploration stage is extensive diamond drilling, generally done from the surface, at the site of a mineral occurrence. In difficult cases it may also be necessary to sink a shaft and drill from underground locations. The purpose of this stage is the provision of information on the size, grade, and other physical characteristics of a mineral deposit. If successful, the delineation program yields a possible economic discovery; that is, a deposit that may be sufficiently rich and large to justify development. On average, only about one occurrence in 20 yields a mineral deposit.

vii Feasibility study. The next stage is a feasibility study, to determine whether or not the discovery is in fact an economic mineral deposit, worth the cost of development. This phase will be dealt with in chapter 6 on Mine Design and Development.

Exploration programs are conducted by junior and producing mining companies and by exploration consulting firms. The average cost of a primary and secondary program (i.e. of finding and delineating a mineral deposit) is estimated to be between $20 million and $40 million. A substantial portion of this cost is taken up by diamond drilling.

Exploration is a highly risky venture, and exploration companies and consultants are generally unable to devote resources to R&D in exploration technology, or even to testing of untried equipment or approaches. Even the larger Canadian-owned companies have, according to Seigel, "been content to allow the foreign-based companies ... to carry the exploration reseach ball for them".[2] New technology has tended to be developed in Canada by equipment suppliers with foreign company or government backing, or to be imported from abroad.

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2. Ibid.

The advances that have been made in geophysical and geochemical techniques in recent decades have been nothing short of revolutionary. In drilling, however, which is a major cost item in exploration, there is almost no research or development being done in Canada. The drilling companies in Canada tend to be small contractors or offshoots of major international companies in a highly competitive market, and have no margin for experimentation that could cost them time or money. Only the major producers of diamond drills, notably Longyear in the USA, have introduced major innovations in drilling. Longyear developed the wire line drill, which eliminates the necessity to raise the drill string every 10 to 20 feet, which is the most significant innovation in drilling in the last 20 years.

INNOVATION OPPORTUNITIES IN EXPLORATION

Introduction

In order to remain competitive, and to continue to supply the resource base to keep the Canadian mineral industry competitive, the exploration sector needs to:

- home in on "targets of interest" - i.e. high grade deposits of minerals which are in demand;
- find a new population of deposits at increasing depth;
- lower the costs of exploration, to compensate for any increasing depth and remoteness of new deposits;
- improve the accuracy and reduce the costs of the delineation stage.

These needs in turn help to identify the top priorities for R&D in exploration:

- basic theories of ore genesis;
- increasing penetration and selectivity of geophysical techniques;
- reduction in the cost of drilling;
- improve the data-collecting productivity and effectiveness from individual drill holes, to reduce the number of holes needed.

These needs will be discussed further in the section that follows, along with other areas of R&D that are also important but perhaps less urgent.

Overall federal government policies related to exploration should recognize that the goal of mineral exploration should be the identification and systematic utilization of resources for optimum economic and social benefits, rather than random finding and developing. Government's contribution to the sector should emphasize geological mapping and resource inventories, as it has in the past, and advancement of the basic theories which facilitate the assembly of this data base.

For further detail on anticipated innovations in mineral exploration, see also:

A.G. Darnley, "Mineral Exploration Technology - Increased Needs and Increasing Opportunities", unpublished internal document, Geological Survey of Canada, 20 July 1983; and

H.O. Seigel, "Exploration 1835-2135", Mining Annual Review, 1985; and "Geophysical Exploration Methods for the 21st Century", paper for presentation at the 13th Council of Mining and Metallurgical Institutions, Canberra, Australia, 11-16 May 1986.

Basic Theories

Advances in the development and communication of basic understanding about how mineral deposits are formed have in the past led to quantum leaps in the efficiency of exploration programs, and can continue to do so in the future. Universities have played a major role in this area of R&D over the years, as evidenced by the following count of thesis topics since 1975, taken from a listing of world-wide theses in R&D and exploration published by the Centre d'Etudes sur les Ressources Minerales in Quebec: basic theories - 575; mineral deposit studies - 94; geophysics and geochemistry - 200.

Communication of these and other research results in basic theories is accomplished through scientific publications and meetings. Some concern was expressed by researchers in industry, and even in universities, however, that there is a deterioration in the quality of basic science teaching and research, a disturbing trend that should be reversed. It was suggested that many teachers may have lost credibility and contact with both the overview of the field and its practical applications, and have become too compartmentalized within their disciplines. It was also suggested that there may be a role here for the Geological Survey of Canada, which is one of the best geoscience organizations in the world, and includes experts whose knowledge and experience spans both theore-

tical and practical applications of geoscience and mineral exploration, and therefore has a great deal to offer university facilities and students. Unfortunately, there was some concern that GSC is at present somewhat isolated, and that budgetary and person-year constraints may increase this isolation in the future.

Geophysics

Geophysics applies a number of techniques, such as seismic, magnetic and electromagnetic, for collecting and interpreting geoscientific measurements and information. Geophysical techniques can be utilized from locations on the surface of the earth, in airborne surveys, or in drillhole applications. Some provide information on visible surface features or at shallow depths, and others are effective down to depths of about 100 metres below the surface.

This is an area of technological innovation in hardware and equipment in which Canada has been a world leader and major exporter. Equipment manufacturers feel, however, that Canada is in the process of losing its competitive edge in this field. They point to the combination of factors, including:

- steeply rising development costs for individual instruments and techniques (averaging over $1 million and 5 years for some recent innovations);
- very high ratio of R&D to sales in the past (about 10 percent);
- sharply declining sales for existing lines of equipment, reducing cash flow for R&D;
- high risk of developing any new equipment, because of the reluctance of industry to accept new concepts, and because of unpredictable shifts in types of exploration activity;
- problems in obtaining government funding for all phases of a development project (further comment below);
- increased subsidization of geophysical R&D in other countries (e.g. airborne EM system at Berkeley, over $1 million per year for over 6 years, as well as strong funding at other U.S. universities including at Tucson, Golden, Salt Lake City, and MIT; Australia, where R&D is coordinated and supported by CSIRO, a federal agency; France is a centre of IP reseach).

The principal need in geophysics at present is an increase in the depth of penetration from the present levels of about 100 metres to approximately 500 metres. It is expected that this improvement can be accomplished by refinements of existing techniques and equipment, rather than totally new approaches. These improvements will generally involve increased data handling and interpretation capability through advances in microprocessors, solid state memories and related software, and refinements in such performance aspects as enhancement of signal to noise.

Equipment for deep penetration can be applied in surface-based, airborne, or down-hole exploration activities. Downhole or borehole logging lends itself to a number of active and passive nuclear techniques and electrical and magnetic measurements which can yield greatly increased information at a range, in any direction beyond the hole itself, that is comparable to the penetration possible from surface. Very little use has been made of this potential up to the present, outside of some coal and oil and gas exploration applications. Among the equipment types now in use for deep penetration and capable of further refinement are: magnetometers, EM transmitters and receivers, IP equipment, magnetic-telluric equipment, seismic reflection, seismic refraction, gravimeters, and temperature probes.

Improvements in existing geophysical equipment for more detailed and varied surface and shallow observations will also be required. These are particularly useful for finding deposits which are difficult to identify by magnetic or electromagnatic techniques, such as deposits of uranium, tungsten, gold, tin, and rare earths. This type of equipment is generally used in surface programs, and some has been developed for satellite remote sensing systems as well. It includes: gamma ray spectrometers and scintillometers, neutron-prompt gamma analysis, portable X-ray fluorescence analyzers, solar and laser-stimulated luminescence, solar reflectance, various radar probes, and better resolution and larger numbers of spectral bands in satellite scanning systems.

Most of the geophysical innovations that will come into use over the medium term are already known today. Some are in need of adaptation to mineral exploration purposes, some are still military secrets, and some are "simply enduring the five to fifteen year period of acceptance into common practice that is, unfortunately, normal to the mining industry".[3] What is needed, therefore, is a program of development and demonstration by equipment manufacturers. External financial assistance will be necessary, in view of the high costs of development, the level of technical risk involved, and the high level of risk in marketing even the most successful products.

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3. H.O. Seigel, "Geological Exploration Methods for the 21st Century", 13th Council of Mining and Metallurgical Institutions, Canberra, May 11-16, 1986.

Drilling

Drilling is used in a variety of ways in the mineral sector: for primary exploration, looking for mineralization; in secondary exploration, for delineation of ore deposits; and in mining, in order to place explosive charges and to make shafts, raises and tunnels. The first two involve recovery of drill core for visual and chemical examination of the rock at depth, and, at $50 per metre, constitute a major proportion of costs in exploration. In 1980, about $100 million was spent on exploration drilling in Canada.

Drilling is the major area in need of R&D in equipment and methods in the exploration field. A significant reduction in drilling costs would be a major advance for the industry. Virtually no R&D is being done on exploration drilling in Canada at the present, although some advances have been made in depth penetration and automation in mining applications. The lack of R&D is attributable to the fact that exploration drilling is conducted largely by small diamond drilling firms operating in a highly competitive and physically demanding field. The operators do not have the capital or the time or the technical expertise necessary to design, test, and promote new approaches or equipment, or, it has been suggested, to operate and maintain highly sophisticated equipment.

This appears to be an area where government assistance in the form of financial support for innovation and demonstration, in a setting free from pressures of drilling schedules, would be both timely and cost-effective. Equipment manufacturers rather than drilling operators would be the appropriate private-sector partners in such a venture. However, a CANMET initiative that ended in 1983 in the area of improved safety in diamond drills led to little or no positive outcome, in spite of the involvement of drill manufacturers and drilling associations.

The major need for advancement in drilling technology[4] is the development of the capability to drill deep, slim holes, at low cost, with minimum deviation, and with rapid recovery of core and other sources of information about the rock encountered (better still, without coring). Basic research is required into alternative methods of hole-making, as well as into refinements into existing approaches. Other or more specific areas in need of innovation, adaptation, or further development are:

- high pressure hydraulic cutting heads;
- development (and hardening) of electronic sensors to monitor thrust, torque, temperatures, rock types etc. to facilate automation and control;

4. See, for example, Proceedings of the South African Drilling Symposium, 10-11 September, 1985.

- development of additional types of sensing capability using, for example, video and fibre optics;
- nuclear, magnetic, electromagnetic, and IP methods for down-the-hole (DTH) sensing of intersected or nearby minerals;
- development of new materials such as ceramics and alloys to resist deviation and operate under conditons of great stress and abrasion;
- microprocessors and software for automation and control, and for rapid interpretation of data recovered;
- improved new approaches such as downhole motors, wireline drilling and high pressure DTH hammers which can increase speed and efficiency of conventional drilling.
- use of synthetic diamond friction bits, so that rotary drilling can replace percussion in small holes.

Advances in drilling will have applications far beyond simply cutting of cost of exploration programs. They will cut costs and improve techniques in mining as well; for example:

- drilling shafts, raises and tunnels;
- preparing boreholes for explosives charges;
- designing shaft collars;
- siting and design for slimes dams;
- siting and designing foundations for mine structures such as headframes and mills.

Beyond mining, applications include:

- foundations for high-rise buildings, silos, and other structures;
- design and construction of docks and other harbour and marine facilities;
- excavation and geological stability in tunnels;
- roads and railway construction, including bridges, slope stability, and roadbed settlement analysis.

Data Handling and Interpretation

The greatly enhanced capability for collecting data, resulting from improvements in geophysics, geochemistry, and other techniques will provide nothing more than an information overload, without an accompanying improvement in microprocessing equipment and in software, for signal processing, data analysis and interpretation, and data reduction to the form

of useful reports and graphics. Integration of a broad range of types of information and rapid evaluation of the significance of the findings for the presence of valuable minerals will greatly increase the efficiency of exploration. This aspect is discussed in more detail in the section on information technologies.

Geochemistry

Geochemistry, biogeochemistry and hydrogeochemistry involve methods of examination of characteristics of materials found at the surface that can throw light on the minerals to be found below. Most are applied in surface exploration programs, although biogeochemical information is also available from satellite and airborne survey data. As in the past, equipment innovations in geochemical applications in exploration will likely involve transfers of technology developed in other sectors (for example, X-ray spectography, dithizone-based chromatography, atomic adsorption, and atomic emission spectroscopy).

Among the anticipated innovations and adaptations in geochemistry are:

- better basic scientific understanding of the dispersion patterns of the elements, both on the surface and in the bedrock, and of the form in which the elements occur;
- application of electrogeochemical methods;
- development of field-usable gas analyzers to study soil gases;
- further understanding of the significance of plant stress information from solar reflectance spectroscopy data, as an indication of the presence of minerals in the soil.

Supporting Systems

Improvements in the efficiency of use of existing and new technologies in exploration will require improvements in a number of areas not exclusively dedicated to the mineral sector, in addition to the information technologies mentioned above. These include:

- satellite navigation systems, to pinpoint the location of airborne geophysical surveys in all weather;
- portable receivers for satellite navigation signals for locating ground-based exploration programs;

- downsizing and hardening of a wide range of electronic, video, and other sensitive equipment for use in the field and downhole;
- marine craft, all-terrain vehicle, and aircraft modifications for survey work;
- field-usable microprocessing computing and display equipment;
- satellite data transmission links;
- lasers, temperature probes, altimeters, and other precision measuring and level systems.

Concluding Comments

Mineral exploration is a highly risky activity, and all the private sector interests involved - i.e. equipment manufacturers, drillers, consultants, and junior and major mining companies - are reluctant and in most cases unable to finance highly speculative long-term R&D. A few exploration equipment manufacturers are the only Canadian private sector firms who have been active in R&D, and they are now finding it increasingly difficult to raise the necessary funds to bring new products to the demonstration stage. They are also facing declining domestic and export markets for their products, as well as increasing competition from abroad.

Mining company financial support in this area is minimal, particularly as the oil and gas companies have sold off their mineral exploration subsidiaries in recent years. As a result, the industry has lost their R&D support, their exploration activities and therefore a significant market for equipment, and their "open-minded and open-handed approach to innovation in mineral exploration".[5]

Although government funds are available for R&D assistance in Canada, the levels of funding have not kept pace with the escalating costs of developing sophisticated new systems from scratch. At the same time, there has been an increase in government support of development of exploration technology in a number of competing countries, including the European Economic Community, the United States (especially the Department of Energy), France, West Germany, the U.K., Australia, and Japan. In many cases this support is based on strategic concerns about security of mineral supplies, rather than or in addition to economic and commercial considerations.

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5. H.O. Seigel, personal communication, September 1985.

Chapter 6. OPPORTUNITIES IN MINE DESIGN AND DEVELOPMENT

GOALS

The goal of mine design is selection of the most cost-effective mining method and sequence of operations. Preliminary activities include preparation of a mineral inventory or geological orebody model of the mineral deposit and preparation of economic models in order to determine the feasibility of proceeding to development. The goal of mine development is the preparation of the pit or underground working areas for mining, and construction of necessary surface facilities, while minimizing the time required and the capital costs.

Although CANMET and some universities have been involved in the development of software and methodology for orebody evaluation and mine design, the bulk of the work in this field is performed by the private sector. Mine design may be performed by a mining company itself, or by a consulting firm. The use of outside consultants has grown in recent years, as companies have cut their in-house staffs in order to cope with economic difficulties. Canadian mining and mine design consultants have taken a leading role in the field of mine design, and are active throughout the world. Canada has some of the most difficult mining conditions in the world, with extremes of weather, very hard and abrasive rock, and remote locations, and its consultants are highly regarded. The larger consulting firms such as Wright Engineering, Kilborn, SNC, or Bechtel (the latter is the only one in this list not Canadian owned) can provide a full range of services, from orebody evaluation to turnkey management of the construction phase. Smaller firms and individual consultants are more limited in their capabilities and scope of their activities, and are more likely to be coordinated or managed by the producing companies that hire their services.

Some mine contracting firms, such as Dynatek, Redpath, and Harrison, will both design and construct a mine for a client firm. These companies are also very active internationally. In addition, there are a host of smaller contracting (i.e. mine construction and shaft sinking) firms operating locally.

DESIGN ACTIVITIES

Mineral Inventory Modelling

Deposit data collected from a variety of sources (principally from drill cores and also using geophysical and geostatistical methods) is integrated

and interpolated to give a picture of the orebody under investigation, in terms of such geological characteristics as location, grade of mineral(s), rock type and density, impurities, seam thickness, irregularities, direction, etc. on a block-by-block basis. This information gives a picture of the nature and extent of the geological ore reserves and, together with other technical and economic inputs, forms the basis for preliminary selection of mining rate and method.

For massive deposits, the geological model is usually a 3-dimensional block type, while more complicated formations will require irregular-shaped models, with groups of blocks representing the ore-bearing seams or deposits. The use of computers for storing, analyzing and interpolating such data has allowed more comprehensive coverage and can in some cases reduce the time and cost of such exercises. Computer graphics, with the capability to zoom in on specific blocks or perform 3-D rotations, have provided increased design flexibility at the same time that they reduce drafting requirements.

In addition to data collected from geophysical, drillcore, and other sources, geological modeling requires the application of knowledge of basic theories of the formation of mineral deposits, and of interpolation and extrapolation techniques.

Economic Modelling

The economic models, or feasibility studies, start from the geological model, and assign both expected dollar values and expected mining costs to each block. In the early stages of feasibility studies, simple estimating procedures are used. As the project approaches the go/no-go development decision, greater levels of accuracy and complexity are required.

Among the sources of information that go into this modeling procedure are:

- the geological data base, including grade and metallurgical characteristics;
- a range of mineral price and demand forecasts;
- estimates of development costs, capital and equipment costs;
- estimates of operating costs for mining and milling, and of expected mining and milling losses;
- costs of smelting and transportation;
- costs of regulatory requirements, and effects of taxation on costs and on revenues;

- inflation and currency fluctuation effects;
- risk analysis for a variety of variables, including geological, market, and political.

Clearly, this task requires inputs and expertise in a broad range of subject matters and disciplines.

The bottom line of the economic modelling activity will be a discounted net present value for the project, and information on the projected rate of return. If the net present value is positive and if the expected rate of return is acceptable, a go decision by management usually follows.

Selection of Mining Methods

The initial choice of open-pit vs. underground mining is relatively simple. An open-pit will result if the deposit is massive in size and shape and is fairly close to the surface, as in the case of many iron ore and coal deposits, or porphyry copper. Frequently, a mine will be developed initially using open-pit methods, with a switch to underground when the waste-to-ore ratio becomes too high.

It is in underground mining that the selection of mining method may become more involved. The variables that influence the choice of mining method include: the properties of the surrounding rock - its hardness or competence; surface sensitivity; groundwater conditions; the characteristics of the ore; the size and shape of the ore deposit; the desired rate of extraction, etc. Among the underground methods generally in use in hardrock mining are:

- room and pillar, for orebodies with competent roof and floor;
- shrinkage stoping, for steep-dipping deposits with strong and competent ore and wall rocks;
- cut-and-fill stoping, for smaller or irregular deposits where there are problems of ground control;
- sub-level blast hole stoping, for large orebodies with strong and competent wall rocks;
- sub-level caving, for larger orebodies lacking competent wall rock;
- vertical crater retreat (VCR), a low-cost efficient bulk method suitable for orebodies with competent wall rocks, increasingly being applied to small orebodies as well as the larger ones.

In other types of deposits, such as coal and potash, other methods such as longwall mining and continuous tunnelling may be appropriate.

Since each mineral deposit is unique, with a very great range of possible physical, geological, chemical, and other characteristics, selection of the optimum mining method requires large quantities of deposit-specific data, a broad range of practical experience and knowledge for a variety of deposit types and conditions, and knowledge of the theoretical and analytical tools for optimization of mine design.

Mine Design

Open-pit mine design techniques, although generally originating outside of Canada, have been developed to a high art here. Open-pit design in effect starts from the bottom, by first establishing the lowest level that can be mined economically, and from there designing a safe and economical series of roads and benches, maximizing the pit slope (within the limits of stability) and minimizing the waste-to-ore ratio, to minimize the amount of waste and overburden must be removed. This type of mining lends itself to very large equipment for handling materials, and, given the appropriate scale of operation and capacity utilization, can be a very low unit-cost method of production. It is also a particularly capital-intensive mining method, one that has been favoured by the capital cost provisions under the federal corporate income tax provisions.

Computerized design techniques and software for open-pit mining are fairly advanced. The best involve fully interactive dedicated computer systems that permit the design of trial pits and the review of plans at each step. According to a 1984 report,

> Existing software covers all phases of an open pit project from feasibility studies to operational planning and control. Engineering applications include soil and rock mechanics programs for slope stability analysis, hydrologic system modelling, and programs to simulate the operation of equipment including draglines, bucket wheel excavators and truck-shovel combinations. Computer-controlled systems are in operation for monitoring and dispatching of haulage trucks. Detailed planning programs cover medium and short term production scheduling, reporting and grade control, and maintenance scheduling and cost reporting.[1]

1. Canadian Mining Journal, September 1984, p. 28.

Underground mine design is more complex, because of the variety of geological conditions, deposit configurations, and other factors that are encountered. Universally applicable software packages are not available for underground hardrock mine design, although many mining companies and consultants have developed or adopted CAD software for specific projects. The lack of commercially available software or even published references to underground hardrock computerized mine planning applications is attributed in part to the fact that:

> the regular 3-D block modelling system is not well suited to the relatively smaller, higher grade ore bodies mined by underground methods. If the ore zone has a well-defined structural or grade boundary, then large model blocks result in unreasonable grade dilution. It is likely that the future will see an increase in the development of customized in-house programs dealing with specific deposits and the special engineering problems they present.[2]

There is a widespread feeling in all sectors connected with the mineral industry that underground hardrock mine design is still too much a heuristic enterprise, in need of a more systematic approach. There is an unfortunate tendency for mine designers to rely too heavily on their own experience, whether in university, or in previous mine design experience, or within a specific region or commodity grouping, and to draw less than they might on the whole range of knowledge and practical experience that has been accumulated throughout the industry. One mining company executive reported that he dealt with this problem by ensuring that his mine design team, whether in-house or on contract, included people with a variety of university and practical-experience backgrounds. In addition, mine design teams have to deal with geological, metallurgical and even marketing data as well as mining engineering problems, and involvement of experts from each of these fields at some stage of the design process is essential, although too frequently overlooked. Increased use of expert systems in the future might help to provide a broader background of information and design approaches which could be integrated with deposit-specific data and software.

In underground coal mining, where the deposits tend to be more amenable to a generalized approach, more has been accomplished in the area of computer-assisted design. In the United States, for example, the "Master Design Simulator" deals with nine major aspects of underground

2. Ibid.

coal mining (geology and reserves; methane generator; roof support; subsidence; production; rail haulage; cost; water generator; and ventilation) for both longwall and room and pillar mining methods. U.K. and western European coal producers have developed programs for simulation, control and monitoring systems for underground coal seams, many of which could be adapted for design use in potash and rock salt mines.

DEVELOPMENT ACTIVITIES

Preparation of an open-pit mine for production involves removal of the overburden or surface soil and rock from the ore deposit, and preparation of sites for disposal of waste from the pit. In many cases, development also requires lake draining and sediment dredging. The methods and equipment are similar to those involved in production. Basically, the operation requires drilling, blasting, and hauling away the overburden, and preparation of the first levels or benches from which production will occur. Little change in method is observable when production is initiated except that, in the production phase, ore is produced as well as waste. Construction of surface facilities for ore preparation and/or milling, storage and transportation of concentrate or product, and disposal of tailings for metallics is usually necessary as well.

For underground mining, the development program involves sinking of the main shaft (or construction of an adit or ramp), with levels and shaft stations established at various intervals. From the shaft stations, crosscuts (horizontal tunnels) are driven to intersect the known ore-bearing areas and to explore for others. Drifts are driven away from the crosscuts, to follow veins and orebearing structures. Raises are opened up to link the levels for a variety of purposes, including access, supply, services, and ventilation. Stopes must also be prepared: these are the actual work areas from which ore is removed.

With the exception of shaft-sinking, most of the development-phase activities are continued throughout the course of actual mining, as the original areas are mined out and new areas opened up. These will be dealt with in more detail, in terms of technology and opportunities for innovation, in the section on underground mining. Shaft-sinking on the other hand is a very specialized skill, generally performed by one of a small group of specialized mine contracting companies. The field is highly competitive, and becoming increasingly so, as mine developments and expansion of existing mines occur less frequently. The firms must operate under very demanding conditions and time pressures.

Mine contractors do no preliminary or laboratory-style R&D, for the simple reason that they cannot afford to. They are in touch with the latest developments world-wide, however, and do bring proven technology (applied on-the-job R&D, if you will) that gives them a competitive edge. In addition, they have to adapt, design, or try out new equipment from time to time. It is a high-risk activity which can cost them heavily if the equipment slows down a development contract, but it is necessary for competitive reasons. Unfortunately there is no tax recognition of the "development" nature of the work, in the form of R&D incentives, and timing pressures rarely permit the paperwork and waiting required in government R&D assistance programs. Nevertheless, it is those contractors who are willing to take risks with innovative equipment who are the leaders in their field.

Redpath, for example, has recently acquired a U.S.-developed shaft-boring machine. The concept is excellent, even though the timing may be bad for experimentation in view of the shortage of new projects. Dynatek has experimented with a microprocessor-controlled raise-boring machine. Unfortunately, Dyntek found that the availability of the equipment was inadequate, as a result of electrical problems, and delays resulted when it became necessary to return the equipment to the manufacturer for improvements. It appears that the equipment manufacturers must carry much of the financial responsibility for development, demonstration, and commercialization of this type of equipment. Most mining equipment, however, comes from manufacturers with headquarters outside of Canada. In some instances, Canadian mining companies have also worked out means of sharing the financial risk of experimentation and proving-out of new equipment and techniques with their contractors.

INNOVATION OPPORTUNITIES IN DESIGN AND DEVELOPMENT

Mine Design

Although Canada's experts are considered among the best in the world in mine design, it is apparent that there is room for improvement in this area, in order to contribute to the industry's efforts to keep its capital and operating costs as low as possible. A number of Canadian projects in recent years provide evidence of serious shortcomings in the design process. For example:

- Quintette, with problems in the geological orebody modeling;
- Goldstream, where the bulk samples were taken underground, and problems arose when they started milling oxidized ore from the open pit;

- Detour Lake, with lower-than-anticipated grades and other problems;
- the Sept-Isle pelletizing plant, which suffered from inadequate information on both quantity and quality of the feed;
- Cantung, which experienced serious grade fluctuations, following a switch to large-scale operations.

These and other cases have been very costly to the industry, and might have been avoided by giving more time and attention to design requirements such as geological orebody modeling, including grade, extent, location, and metallurgical characteristics.

Basic Theories for Mine Design

Work needs to be done in universities, possibly with assistance from the GSC, in basic theories and methods of geological orebody modeling, including useful sources of input data and interpolation and extrapolation techniques, making fullest possible of computer analytical and graphics capabilities. This expertise needs to be passed on to the practitioners in the industry as well, through graduating students and through mid-career training. The latter is particularly important, in view of the very small number of new employees being taken into exploration groups at present.

More basic research is also needed in rock mechanics, to assist in designing mines in a manner that will avoid, as far as possible, problems of rockbursts and ground control.

Software for Mine Design

Software for underground mine design is a major area of opportunity for innovation. As noted above, it is most likely to evolve on an ad hoc basis within companies, rather than in generalized configurations that can be sold commercially to a wide variety of companies. There will therefore be a need for communication between companies on the specific software packages that have been developed, in order to share programs where similar problems are encountered and reduce unnecessary duplication of effort.

Among the software applications for underground mine design that need to be developed or improved are programs for modeling and/or simulation of: irregular veins and deposits; layout of levels, drifts, stopes, etc.; general planning and scheduling; materials handling; ground control and all aspects of rock mechanics; and ventilation.

In addition to company in-house efforts in this direction, much could be done by university departments, which should generally make better use than they do at present of the multidisciplinary talents available to them. Teams with expertise in geology, mining, mineral processing, extractive metallurgy, cost analysis and computing skills should turn their efforts to some of these design needs. Unfortunately, NSERC and other funding sources (not to mention university departments) are usually discipline-oriented, and this creates difficulties in obtaining cooperation and team funding, even where it is obvious that interdisciplinary skills are required.

CANMET has been involved in mine design software, as noted previously, with the development of SPOC for simulation of open pit ore and coal processing, with rock pillar design and analysis programs, and with the Canada/Manitoba Mineral Development Agreement work on computer-assisted design for underground mining.

Mine Development

Areas of opportunity for innovation in mine development hinge on the needs to lower the cost of development, and shorten the development time. Because the equipment used for development is mainly imported, much of the innovation takes the form of incremental upgrading of existing equipment and of technology transfer from other countries and from other areas of activity, such as construction. Dynatek, a mine contracting firm, has attempted to overcome some of the obstacles to innovation in mine development through a new type of joint venture contract with the mine owner, Lac Minerals, in sinking a deep shaft at the Macassa Mine.[3] The owner shares in the capital cost of equipment and in any profit or loss on the contract. The contractor reduces his risk and is required to put up only half the capital required to execute the project. The arrangement permitted experimentation in several aspects of the construction that would have been difficult or impossible under a traditional contract.

New bulk mining methods such as vertical retreat mining have already lowered mine development costs. These will be discussed in more detail in the section on mining. Other new approaches for the future, such as continuous mining methods and solution mining, are still in the high-risk research category, and in need of extensive R&D aimed at developing equipment and technique in order to take advantage of the im-

3. See W.R. Dengler et al., "Innovations highlight conventional deep shaft", Canadian Mining Journal, May 1985, pp. 89-99.

provements they appear to offer. For example, in solution mining, it is expected that development costs will be unacceptably high until better methods can be found of achieving the fragmentation needed for the method to be effective. In continuous mining as well, speculative research into a number of types of rock-breaking techniques may be required. Application of softrock techniques such as tunnel boring to hard-rock mining is another area of opportunity, one that will require, for example, a solution to the problem of equipment jams caused by the fall of fractured rock. It is particularly in these areas of long-term high-risk speculative research that the private sector might be expected to turn to cooperative efforts and joint ventures, and to seek government support and R&D assistance.

Chapter 7. OPPORTUNITIES IN MINING

GOAL

The goal of mining is the production of ore in the case of metallic minerals, or some form of crude mineral product in the case of industrial and other nonmetallic minerals. About 50 percent of the cost of producing a final metal or mineral commodity arises in the mining stage. In order to remain competitive in mineral markets, mining companies must constantly improve productivity of both capital and labour, and thereby reduce or at least maintain unit output costs in spite of inflation in the unit cost of inputs. Producers are also required to meet increasingly stringent health and safety and environment protection regulations, while maintaining their competitive position.

METHODS AND EQUIPMENT: STATE OF THE ART

The mining method selected for any particular mineral deposit will depend principally on the deposit type, and the depth at which it is found. Deposit types may be broadly classified as:

1. massive or vein deposits, generally associated with nonferrous metallic ores. They can be highly variable in size, shape, and inclination;

2. bedded deposits, associated for example with coal, salt, iron ore, potash, asbestos, and, in Ontario, with uranium. They tend to be horizontal and fairly uniform in thickness;

3. unconsolidated deposits, such as placer gold deposits, alluvial tin deposits, or industrial sand and gravel.

The mining methods employed to recover minerals from various types of deposits can be classified as follows:

1. Surface Mining

    a) open pit and strip mining - e.g. bedded deposits such as coal, iron ore, or any deposits close to surface

b) placer mining - heavy metallics in alluvial deposits - e.g. gold or tin

c) solution mining (one potash mine in Canada) and leaching (e.g. for metallic ores and tailings and being studied for uranium). Both can be used on the surface or underground.

2. Underground mining

a) soft rock (e.g. coal, potash - bedded deposits)

b) hardrock (e.g. nonferrous metallics, massive sulphides, lode gold)
various small-stope methods - for small and or irregular deposits
bulk methods - in competent rock, generally for larger deposits

Open-pit mines produced 3 to 4 times the volume of ore produced by underground mines in Canada over the period 1970-80. Although coal production has grown, open-pit metallic ore production has fallen somewhat, in recent years, with mine closures in B.C. in base metals and in iron ore in the Labrador Trough and Ontario. The stripping ratio (i.e. waste to ore) has increased over the same period, particularly for metal mines, which showed an increase of 30 percent from 1969 to 1980.[1]

Some of the relatively low-grade high-volume open-pit operations will be exhausted or become uneconomic over time, due to rising strip ratios and production costs. At the same time, new exploration efforts are being directed increasingly toward finding smaller higher-grade deposits close to infrastructure, because any resulting mines will have lower capital and operating costs, and be more competitive. It therefore seems likely that the relative importance of open-pit mining will decline, for metallics at least, if not for coal and industrial minerals, over the medium term.

The mining methods that appear most susceptible to major improvements through technological innovation are:

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1. B.W. Mackenzie and R. Pakalnis, Mineral Technology Transfer: Evaluation of the CANMET Pit Slope Project (Kingston: Centre for Resource Studies, 1985).

- first, underground soft rock mining, where significant advances have already been made;
- second, underground hardrock mining, for both short-term upgrading of current technology and long-term development of new approaches;
- and third, mining by solution or by leaching, including bioleaching, for low grade ores in the short term and possibly more fundamental advances over the longer term.

Open-Pit Mining

Open-pit mining requires the removal of overburden from the surface above the ore deposit, and then removal of the ore and waste rock. The overburden, especially the topsoil, may be set aside for use in reclamation. The waste rock is separated from the ore and placed in waste dumps, and the ore is removed for beneficiation and further processing. The overburden is removed by a variety of types of digging or excavating equipment, preceded by drilling and blasting if it is not made up of loose soil. The ore is removed by drilling, blasting, and mucking procedures. Because the deposits are massive and operations are in the open, rather than in small, irregular areas as in underground mining, they lend themselves to large-scale methods using very large-capacity materials handling equipment such as shovels, trucks, and sometimes conveyors.

The open pit techniques used in Canada are well advanced, and unlikely to see radical changes in approach in the foreseeable future. For example, optimization of pit-slope angles and minimization of waste-to-ore ratios have been accomplished to a significant extent, an effort in which CANMET played an important role.[2] Major advances have also been made in the development of software for planning and scheduling of ore removal, and in techniques and control for blasting.

Core equipment for open pit mining includes very large capacity excavators, shovels (e.g. 10-15 cu yd), trucks (up to 100 tonnes), and crushers, plus earth-moving equipment such as bulldozers and graders. The mining equipment can be used in other applications, particularly oil sands mining, and the major market is for the earth-moving equipment is in the construction industry. Virtually all of this equipment is imported from other countries such as the USA, the U.K. and West Germany.

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2. B.W. Mackenzie and R. Pakalnis, Mineral Technology Transfer: Evaluation of the CANMET Pit Slope Project, CRS Technical Paper No. 4, (Kingston: Centre for Resource Studies, 1985).

Equipment innovation needs for the medium term centre around increased remote control and automation, through advances in sensors, microprocessors, and computing software. There is also a need for improved materials handling systems, such as increased use of conveyors for handling both waste and ore. Mobile equipment in the pit will improve flexibility: for example, mobile crushers, ore sorters, grade separators, and water control system. For harder rock, application of continuous methods such as bucket-wheel excavators is a possibility.

Underground Mining

Softrock Mining

Mining methods in softrock underground deposits such as coal and potash have gone through revolutionary advances in techniques and equipment in recent decades. The introduction of multi-million dollar longwall and continuous tunnelling equipment, with supporting systems and ore conveyors, have gone a long way towards establishing continuous mining as a reality in some of the newer and better equipped mines. Work is under way, particularly in the U.K., Germany, and USA, to move towards computerized automation of such continuous systems. Improvements in rock breaking and drilling techniques in softrock mining have also been made, through the use, for example, of high-pressure water jets, with and without abrasives. These improvements can be expected to find wider application in softrock mining, to the extent permitted by a number of constraints including: the availability of capital for refitting or expanding existing mines and for opening new operations; the willingness of management to change to newer mining methods; and the suitability of deposit types and configuration to the continuous techniques.

It is also possible that continuous mining innovations may be transferred over time from softrock to hardrock mining, with appropriate adjustments for the more difficult mining conditions. The constraints to technology transfer mentioned above will apply, in addition to technical constraints imposed by the harder rock and the greater irregularity of deposit configurations.

Softrock deposits of minerals such as coal and potash that are too deep for surface mining are still being mined by a wide variety of underground methods including:

- the traditional cycle of drill, blast and muck;
- continuous tunneling, in some potash mines and just introduced in Canadian coal mining;

- hydraulic mining, using water under high pressure to dislodge and slurry coal;
- solution mining, suitable for soluble salts and in use in one potash mine in Saskatchewan;
- longwall (mechanical) mining.

The characteristics and shape of the softrock ore deposit usually permit the use of selective "bulk" mining, with large open tunnels and working areas, and a minimum of smaller workings such as levels, cross cuts, drifts etc. As noted, continuous mining equipment is now in use in some potash mines, and a tunnel-boring machine is in use in the Donkin-Morien coal mine in Nova Scotia. Innovations such as longwall mining and its related equipment have generally been imported to Canada "as is" through equipment purchases. A significant exception is the tunnel boring machine adapted for Canadian coal mining by Lovat Tunneling Equipment Inc. of Rexdale, Ontario, with $5.5 million in federal government support. In addition to direct financial support, the federal government has assisted with the demonstration phase of the adaptation by putting the machine to use in the Donkin-Morien mine.

Hardrock Mining

When most people think of mining, they think of underground hardrock mining. In its most traditional form, it involves sinking a shaft to the lowest proposed working level, and adding horizontal drifts and crosscuts to reach the ore, which is removed from working areas called stopes, leaving behind pillars of ore as supports. The working levels of most operations are fairly close together and fairly small stopes are mined out using a wide variety of methods. In all of these methods, the ore is fragmented by a cycle of drilling and blasting. The broken ore is mucked out of the stope, carried to the ore chute, dropped to the crushing level, crushed, and hoisted to the surface. A great deal of time and effort goes into the process of ground conditioning of service areas, approaches and stopes, to prevent rockfalls from the walls and "backs", or ceilings, using rockbolts, anchors, screens, and shotcrete.

About 40 years ago, improvements in drilling techniques and equipment led to a Canadian innovation, blast-hole stoping, which is now used in some underground mines with massive deposits and competent wall rocks. This open stoping method is more economical than using smaller stopes, as fewer work areas and pillars are required. More recently, another bulk mining method, vertical crater retreat (VCR) has been in-

troduced into a few Canadian mines. It too is suitable for massive deposits, although it is less appropriate for small or irregularly shaped vein deposits. Bulk mining methods, because they require fewer and smaller workcrews, and fewer working levels, stopes, and related services and facilities, are much more economical than traditional mining methods. In Inco's Copper Cliff North research mine, VCR mining has been able to accomplish the following objectives:

- a safer, easier mining method;
- a 300-percent improvement in productivity in terms of tons per man-shift at a reduced capital cost;
- concentration of all production activity on two levels (upper: drilling and blasting; lower: draw point, crusher and hoist);
- no pillars left behind for secondary mining.

The method, which can be applied to existing mines as well as new developments, has been adopted in a number of other mines, by Inco and by other companies. Inco spokesmen feel that application of this method in new mines can reduce development costs by as much as 60 percent.

Development of VCR mining has required advances in drilling technology (particularly in controlling the direction and location of the bit in a very long hole) and in explosives technology. Remote controlled scoop-trams have also been introduced, because of the danger of falling ore at the drawpoint. Work is in progress in the private sector in Canada and elsewhere on more efficient muckers, crushers, and materials handling equipment to complement this mining method. Some problems with ground control and backfill remain to be solved.

Canada's technological preeminence at present seems to be mainly in mine development and in underground bulk methods for massive deposits. In the smaller inclined vein-type deposits, Sweden seems to have an edge. Swedish innovations have been transferred fairly rapidly to Canadian operations, through equipment purchases and through joint ventures.

In the area of mining equipment manufacturing and innovation, Canada is an importer, relying heavily on countries such as Sweden, Finland, the USA, U.K., and West Germany for core mining equipment such as drills, raise borers, mucking machines, ore moving cars and trucks, etc. (see appendix B).

Some of the areas in need of improvement in underground hardrock mining, in order to cut costs, improve productivity, and meet health and safety requirements, include:

a) in the short term:

- crushing and materials-handling of broken ore and waste (perhaps the biggest bottleneck in conventional underground operations);
- communications - between men and between equipment;
- ventilation and increased electrification of equipment;
- improved directional control of long narrow drill holes for bulk mining blasting;
- remote control for equipment in hazardous locations;
- better understanding of the associated rock mechanics;
- continuing improvements in backfill technology and practices.

b) in the medium term

- a move towards automation of some aspects of operations;
- extension of bulk methods to a greater variety of conditions.

c) in the long term

- continuous mining methods, with new approaches to fragmenting rock;
- automation of most aspects of operations.

Other Mining Methods

A variety of other mining methods are in use or being contemplated for future use. These include the following.

- Solution mining. As mentioned above, this is suitable for recovering soluble salts such as potash.
- In-situ leaching. Some use is already made of in-situ leaching for recovery of uranium ores from previously mined stopes. The method could also be applied to recovery of low-grade copper and some other base metal ores, if an economical method of fragmentation can be developed.
- Hydraulic mining. As noted, some coal mines use hydraulic methods for dislodging and slurrying broken coal. It is also used to dislodge soil, for example along river banks, in some placer deposits.[3]

3. Canadian-developed technology for hydraulic mining of coal is now being marketed worldwide, although the one Canadian mine where it was used has since been closed.

- Dredging. Used for underwater alluvial metallic deposits and for sand and gravel.
- Ocean mining. Recovery of nonfuel minerals from the continental shelf and ocean depths is still relatively far off in the future, except for some dredging of aggregates. It will require innovations in a broad range of methodology and equipment, for both shallow and deep water applications.

Except for leaching methods, both chemical and biological, Canada is doing little in the way of innovation in these other mining methods.

Mining Equipment - Present Sources

In 1982, imports accounted for 75 percent of all mining equipment used in Canada, as compared with 73 percent in 1980 and 50 percent in 1965. The heaviest concentration of imports was in the larger and very costly lines of equipment, primarily for open-pit operations. Major sources of mining machinery and equipment imports in 1970 and 1980 are shown in table 37.

Table 37

MINING MACHINERY AND EQUIPMENT IMPORTS BY MAJOR COUNTRY OF ORIGIN, 1970 AND 1980

Country of Origin	1970	1980	Average Annual Growth (%)
	$ millions		
USA	69.3	291.0	15.4
West Germany	3.4	33.6	25.7
United Kingdom	8.3	17.2	7.6
Sweden	1.2	11.5	25.4
Finland	n.a.	3.3	n.a.
Japan	n.a.	2.6	n.a.

Source: ITC, A Profile of the Mining Machinery and Equipment Sector in Canada, March 1982, p. 25.

Industry, Trade and Commerce in 1982[4] gave the following estimation of the potential of the Canadian equipment industry for supplying the

4. ITC, A Profile of the Mining Machinery and Equipment Sector in Canada, March 1982.

needs of the Canadian industry, a potential that was not being realized, according to the figures above.

1. In open-pit mining - Canadian capability for about 50 percent of requirements

   - very weak in drilling equipment, except for drill rods and materials for rigs;
   - drag lines - no Canadian producers for drag lines, but some for components - perhaps 30 percent;
   - feeders, stackers, reclaimers - up to 50 percent;
   - power shovels, front end loaders, graders and bulldozers - bulldozers and larger shovels and loaders are all imported;
   - off highway vehicles - good, up to 300 ton capacity;
   - conveyor systems - more than 90 percent.

2. Underground mining - Canadian capacity for supplying close to 75 percent of equipment, except for coal, where a few large foreign firms dominate.

   - hoists, cages etc., about 90 percent;
   - drilling equipment - 70-75 percent, except for down-the-hole drills which have only recently become available from Canadian sources and long hole drills which are not made here;
   - raise climbers - about 80 percent of components;
   - extraction and bulk materials handling equipment - about 60 percent, except for locomotives and overhead loaders which are imported;
   - pumps - about 80 percent Canadian content;
   - crushers - virtually 100 percent Canadian. Coal crushers are produced under licence in Canada.

INNOVATION OPPORTUNITIES IN MINING

Introduction

In order to remain competitive, the Canadian mining industry must produce mineral products that are in demand in world markets, and produce them at a price per unit that is competitive with producers elsewhere - so competitive, in many instances, that such constraints as nontariff barriers, trading blocks and procurement-policy restrictions can be over-

come. In order to accomplish this, unavoidably high-cost mines must be closed. Costs must be brought down to competitive levels in other high-cost operations, and kept down, in spite of inflation in input-factor costs but not in metal prices, in marginal and low cost operations as well. Continual innovation, either developed here in the mining industry or transferred promptly from other sectors and other countries, is essential.

Very long lead times are required to open a new mine or to upgrade an existing facility substantially. At the same time, metal prices and demand are subject to rapidly changing cycles that require quick response from producers. In coping with the resulting problems of recovering large capital investments as well as covering current costs in the face of fluctuating revenues, the producer with the most advanced technology will have a decided advantage, all other things being equal. For this reason, it seems wise as a first step, to facilitate rapid technology transfer into the industry for innovations developed elsewhere, and for the longer term, to encourage innovation within the Canadian mineral industry.

Basic Research

Basic research in earth sciences and other studies essential to the recovery of mineral resources is a long-term high-risk activity which, in the course of developing basic understanding, will also occasionally provide insights that can be applied to the development of new methods and technology. It is generally conducted in universities, with government financial support through programs such as NSERC grants. Some basic work is also conducted at or supported by CANMET, although CANMET's emphasis is generally in applied science. Although this list is intended to be illustrative rather than exhaustive, the basic research topics that may contribute to improvements in mining methods, technology, and equipment include the following.

In Physics

- nuclear physics studies for development of sensing devices and measuring devices
- solid state physics for studies of properties of materials, stress in solid materials, and low temperature properties of materials

In Geology

- ore genesis
- ore reserve estimation methodology

- structural geology, including the response of rocks and rock systems to deforming forces (i.e. rock burst studies)
- hydrogeology and hydrogeochemistry - movement, occurrence and quality of surface and ground waters

In Mining
- rock mechanics (rockbursts, fragmentation, cutting, abrasion, strength, etc.)
- behaviour of explosives, thermohydrodynamics
- ventilation principles
- leaching - chemical and biological
- computer simulation for underground mining and for benefication processes

In Mechanical Engineering
- new materials technology for improved equipment
- fluid mechanics

In Biology - probably jointly with earth sciences researchers
- genetic engineering of thiobaccilus ferrooxidans and other biological leaching agents
- studies of effects of parameter changes on biological leaching agents

Mining Methods

Applied research in mining methods is conducted in university mining departments, in government research facilities, and on site at operating mines. Universities (and, to some extent, government facilities) are handicapped in practical aspects such as experimentation and demonstration related to mining methods, which do not lend themselves to laboratory-scale efforts or the short terms of most research grants. Facilities such as Queen's University's blasting site and CANMET's laboratories at Elliot Lake and Sydney are useful exceptions to this generalization.

Opportunities for innovation in mining methods lie chiefly in the areas of management, bulk mining, continuous mining, and, for the longer term, ocean mining.

Management Methods

Management of mining companies, particularly of the smaller producers, tends to be in the hands of a small group of technically trained people. Because the industry is not in an expansion mode, most managers have been in the industry a long time, and many have not recently been exposed to new concepts in management, in computing, and in some cases even in mining technology. There is an important opportunity, therefore, for mining management to reinforce its skills through upgrading courses, participation in management and technical sessions at scientific and professional meetings, reading the literature, and bringing in new employees specifically to bring in new skills in this area. Without the support and active participation of management, all efforts at innovation and technology transfer within any given operation will be severely handicapped.

Government assistance in this area will lie chiefly in the continuing support of scientific and technical associations and journals. There is also a role for government through increased support for or presentation of specialized seminars aimed at management level. Executive interchange programs and tax incentives relief for mid-career training could be broadened and receive greater emphasis.

Bulk Mining Methods

Expansion of the use of bulk mining methods for underground mining, such as vertical crater retreat and blast-hole stoping, will improve productivity in a select group of mines blessed with relatively large deposits and suitable ground conditions. Bulk mining is a technique in which Canada has a comparative advantage, in terms of familiarity with the technology, and consequently transfer of the technology within the industry, from one company to another, should be relatively easy to accomplish.

Government assistance in this activity might take the form of tax incentives to encourage investment in conversion to more efficient mining methods. However, it is difficult to imagine a more compelling incentive than the published figures on improvements in tons per manshift (plus associated reductions in capital costs) released by companies that have made the change. Because of the cost advantage in both the development stage and during production, any new mines with suitable geological conditions will most likely routinely adopt bulk methods.

Optimization of bulk mining methods will require improvements in a number of kinds of equipment and techniques which will be discussed in more detail below. These include:

- drilling techniques and equipment to improve accuracy of placement of long holes;
- explosives and blasting, for accuracy of the "slicing" effect, improved fragmentation of ore, while not endangering the surrounding rock or the structural installions;
- remote control, particularly for operations under the open draw point;
- portable crushers, to permit the use of conveying systems and to eliminate the need for a single permanent crusher to which all ore must be moved before hoisting.

Continuous Mining Methods

Continuous mining is already a reality in some softrock mines. There is an opportunity for eliminating the inefficient and labour-intensive cycle of drill, blast and muck that is presently the heart of traditional mining methods in hardrock mining, for both open-pit and underground operations. It will require entirely new methods of breaking rock, probably ones that do not involve explosives, and of continuous removal, for example by conveyor, of the broken rock to the mill. As a first step, continuous ore removal would be a major advance.

An alternative approach to continuous mining may involve in-situ leaching, perhaps in combination with hydraulic or high pressure water jet techniques for rock-breaking followed by introduction of chemical or microbial leaching agents. The waste might remain in place or be removed in slurry. Some of the hardware innovations that will support both these approaches are described in the section on equipment below.

The fundamental problem seems to be finding an efficient means of breaking rock, and reducing the ore to fragments of manageable size for milling or leaching. The solution to this problem will require a long-term high-risk research effort, one that may be beyond the resources of individual mining or equipment companies at the present time. Cooperative industry efforts and joint ventures will be required. Federal assistance that encompasses all phases, including research, development, commercial application and break-in period, would be appropriate.

Development work in continuous mining is well under way in Canada for some softrock applications, as noted previously. Other developments, such as feeder-breakers for continuous strip mining of coal are already being marketed by U.S. and U.K. firms. In hardrock applications as well, some Canadian mining firms have been working on continuous methods. For example, Inco has established Continuous Mining Systems,

to develop some of the supporting equipment required; J.S. Redpath and Kiena Gold Mines are testing a mechanical boring machine in hardrock at the Kiena mine; Noranda Research has done studies of in-situ leaching of copper ores; Denison and Rio Algom are experimenting with the use of in-situ leaching methods for the recovery of uranium from low-grade ore in mined-out stopes.

Continuous mining methods will lend themselves to an increasing application of remote control, automation and robotics. Among the factors facilitating automation will be:

- the continuous advance of the single working face, rather than a disjointed and disconnected collection of working faces in various stopes;
- methods and equipment which can be designed "ab initio" with automation in mind, rather than evolving from traditional approaches which may be less suitable;
- fragmentation of ore right at the working face, to a degree that permits continuous conveyance and monitoring of the ore from the face to the mill (or storage location for further shipment);
- the eventual elimination of a blasting phase with associated concussion problems, which are a particular hazard to delicate electronic equipment and sensors;
- the elimination of the stop-start nature of ore production associated with drilling and blasting.

Ocean Mining

The ocean is a new frontier for mining activities, one which is still uneconomic to exploit, in most instances, but which offers future potential. Canada's continental shelf and deeper offshore regions contain deposits of gold, silica sand, sand and gravel, ilmenite (titanium ore), magnetite, zircon and carbonate sands. These can be recovered using existing technology in shallow areas, once they become economic. It has been predicted that the first three commodities may be exploited in Canada's offshore to a significant extent by the end of the century.

Research into methods of recovery of deep sea minerals, chiefly manganese modules containing manganese, nickel, copper, and cobalt, was conducted over the 1960s and 70s by consortia from a number of countries, principally the United States, Germany, Japan, UK, France, and the Netherlands. Several Canadian companies, including, Inco, Noranda, and Falconbridge, have been involved with various consortia. It has

been estimated that about $500 million has been spent on such studies to date.[5] There is a need at present for plotting and mapping of underwater deposit areas, using video techniques among others. Another area in need of R&D is drilling technology for deep water exploration. Techniques developed for ocean drilling for the petroleum industry will not generally be suitable for mineral exploration, which will require mobile equipment, able to operate at great depths to produce shallow closely-spaced bore holes. Mining techniques and equipment for recovering metallic nodules and crusts must be developed and evaluated, comparing, for example, the effectness of various pickers, draggers, drag rippers, impact chisels, cutter heads, and perhaps hydraulic and jet cutters. Energy-efficient methods of lifting the ore from the ocean floor must also be developed, as well as means to minimize pollution from waste sediments.

However, funds for geological surveys and mineral reconnaissance, as well as ocean mining technology, have been curtailed in recent years because of current overcapacity in base metal production facilities. A second constraint on R&D expenditures has been the difficulties encountered in drawing up and ratification of the Law of the Sea Treaty. No major industrialized nation has yet signed the treaty, making its application virtually impossible, and creating an air of political uncertainty in addition to the technological and market uncertainties already in place.

Mining Equipment

There is a broad range of opportunities for innovation in core and peripheral equipment to support both traditional and innovative mining methods. This section will look at types of equipment innovation that hold promise for particularly significant contributions to the industry, with an emphasis on core equipment but looking at the equally essential but perhaps more widely marketable peripheral equipment as well.

As noted above, a significant proportion of the equipment used by the Canadian mineral industry is presently imported, and will continue to be for the foreseeable future. For this reason, much of the equipment innovation will continue to take the form of technology transfer through purchase of proven "state of the art" equipment from foreign supplies.

Some of the constraints to development of Canadian capability in fundamental innovations in the mining equipment industry have been and/or will be the following:

5. B. Lancaster, "Lack of cash slows R&D for Ocean Mining", American Metal Market, 1 November 1985.

- strong established position of existing foreign-owned manufacturers with world-wide exports of mining equipment;
- shrinking market for mining equipment world-wide, due to over-capacity, lack of cash flow for refurbishing plant and equipment, etc.;
- increasing subsidization by other (competing) countries of research and development in mining equipment;
- catch-22 problem for Canadian-based manufacturers of the difficulty of making export sales before service facilities are established, and vice versa;
- lack of R&D in Canadian branch firms;
- the high cost and high level of risk entailed in developing sophisticated new equipment, for an industry that is extremely cyclical and therefore an unreliable customer as a whole;
- the difficulty for Canadian manufacturers of testing and proving up new equipment that requires on-site demonstration, in a very conservative industry;
- the inadequacy of Canadian government support programs for joint ventures in equipment innovation, e.g. industry-university, industry-CANMET, or between companies (or the lack of proposals to initiate such support);
- the absence of government support programs designed to see innovation projects through from conception to commercialization;
- the fact that mining equipment seems to fall between the cracks in government support programs - it is specifically excluded from EMR support programs, and largely ignored by DRIE programs.

Nevertheless, among the equipment needs and opportunities identified below, there is no reason to expect that appropriate corporate and federal policies cannot be developed to turn some areas of comparative advantage in terms of knowhow and experience into market advantages for Canadian innovation, commercialization, and domestic and export sales.

Rock-Breaking Equipment

Rock-breaking and penetration is essential for opening the working areas and access shafts and tunnels in an underground mine, as well as for removal of ore. Great strides have been made toward development of shaft-sinking and raising boring machines, and further improvements in this area will generally be evolutionary, leading to increased automation and reliability. Continuous tunneling machines for softrock mining are

well established, and will likewise see incremental improvement rather than major new approaches.

The conventional approach to rock-breaking for tunneling and ore removal in hardrock mines is the drill-blast technique. Multi-boom jumbos, hydraulic drills, and other improvements have increased the efficiency of drilling operations over recent decades. Innovations in long-hole drilling and in explosives materials and handling have been an essential part of the adoption of bulk mining methods. Further refinements, such as in the control of direction and location of drill bits in long hole, and in automation of the drilling procedure, the addition of a variety of down the hole sensors, and down-the-hole motors, will be largely incremental in nature.

Many of the improvements will come from the established drill manufacturers and will be imported into Canada. For example, Sandivik Rock Tools, a Swedish company that puts 4 percent of its annual cash flow into R&D, has developed "speedrods" which improve drilling efficiency (as much as 23 percent), improved bits for longer life (over 100 percent), a "Guide Bit" for reduced deviation down the hole, and Unipass, a new bit that increases penetration rates and reduces extraction problems. Boart, another European manufacturer, has recently entered the Canadian market with its hydraulic drills, claiming a number of improvements including high reliability, low maintenance costs, smooth and relatively quiet operation, and improved bit life, as well as a broad range of available designs to fit various requirements. As in other equipment areas, the hydraulic drill market is relatively small in Canada (estimated at 75 units in 1985, of which all but 15 were purchased by the mining industry) and it is presently served by a small number of multinational manufacturers with broad product lines and strong sales and service capabilities within Canada. Entry for a new Canadian-based equipment firm would likely require some sort of sponsorship by or joint venture with a mining company as a guaranteed purchaser.

Some domestic drilling improvements are already in progress from Canadian mining company projects currently under way. For example, CANMET reports the following drilling studies in progress or under consideration in 1984:

- Denison Mines - conversion of drill jumbos for up-hole drilling;
- Inco (Copper Cliff) - deviations in long 6.5" diameter drill holes, and development of an in-the-hole machine;
- Falconbridge - automation of drill rod handling and of down-the-hole drilling.

There is an opportunity for development of made-in-Canada technology providing a new approaches to rock breaking, ones that will eliminate the need for blasting and the associated problems of concussion, ground control, and ventilation. Such new approaches will require applied research and testing, will be costly, and will be high risk. It will take a long time to identify which are the promising areas, and which should proceed to the stage of commercialization.

There are no Canadian equipment manufacturers in place to fund this sort of effort, and drilling firms, as mentioned above, are not in a position to fund or conduct equipment development activities. Established mining firms might be able to fund this sort of development, but it would likely have lower priority than projects with lower risk and more immediate potential gains. University research would require industry assistance at the demonstration stage, and, of course, is dependent on government funding. It seems likely, therefore, a possible approach to development of new rock breaking techniques and equipment might, as in the case of continuous mining methods in general, involve industry and university-industry joint ventures, assisted by government financial support.

One such project with exactly this configuration has been proposed by HDRK Ltd., originally a consortium of four major mining companies (Kidd Creek, Inco, Falconbridge and Noranda) established specifically for joint R&D ventures. HDRK proposes to study high-pressure water jets as a means of rockbreaking. Other new approaches currently under consideration in Canada include:

- Cominco's R&D into a continuous mining machine that could operate in hardrock headings dipping from +5 degrees to +85 degrees, and into the use of ore sorters in conjunction with continuous breaking of rock.
- Laval University studies of laser applications in rock breaking and penetration.

Opportunities in blasting involve the development of understanding of the behaviour of explosives, new handling techniques, and new explosive materials. Improvements will be incremental rather than revolutionary, leading to increased efficiency of operation, better configuration of the remaining surfaces, better fragmentation, and increased safety related to ground control and air quality. Research is presently being conducted by Inco, Falconbridge, Cominco, Queen's University, and by CANMET's Canadian Explosives Act Research Lab, as well as by the leading explosives manufacturers, CIL and Dupont.

Materials Handling

The second major type of equipment required in mining is for moving of broken ore and waste rock. Traditionally, in underground hardrock mining ore is picked up by shovels, scooptrams or LHDs, placed in trucks or rail cars, transported for various distances on the working level, dumped to the crusher level, conveyed past the crusher to the hoist, hoisted to the surface in a skip, dumped onto a conveyor, and moved to the mill or to storage piles. In open-pit mining, shovels and trucks are the major items. Significant improvements in ore capacity have been made in recent decades, and in improved design such as low-profile LHD vehicles for underground work. Until the mines have equipment in place permitting a shift to a conveyer-based system from the production face (as is found now in potash mines), the opportunities for improvement are largely incremental, and will involve such changes as increased reliability and ease of maintenance, additions of remote controls, particularly for underground work, and greater use of electrification.

Electrification is now widely available for trucks in open pits, and for scooptrams underground. It offers advantages of efficiency and improved control for open-pit trucks. Underground, it adds the advantage of elimination of diesel exhaust fumes and fuel storage. For the medium term, electrification of vehicles will require wires, with the associated transformers and other services. Development of compact and efficient battery packs for vehicles will be a longer-term effort, and will originate outside the mining industry.

Shovels, trucks, scoop trams, LHD vehicles are mostly imported, although some units are built or assembled in Canada. The presence of established multinational firms and their service and sales agencies throughout Canada makes it difficult to establish a major Canadian presence in the manufacturing of mining vehicles in this highly specialized, competitive, and rather small market.

Reliability and durability of hoisting and conveying equipment are also areas of opportunities for incremental improvements in materials handling. Here the possibility of Canadian participation in manufacturing is greater, since the individual units are relatively small and in many cases have applications beyond mining, providing a larger market base.

The major area of opportunity for Canadian participation in development and manufacture of materials handling equipment lies in more innovative approaches to materials handling. Continuous handling techniques such as conveyers and slurry pipelines would eliminate a number of loading and unloading activities. They also offer improved possibilities for in-stream crushing and sorting of materials and for control and automation

of mining activities. Canada has considerable experience in overland conveyers for minerals, and a 500-tph vertical conveyer, employing a 2-belt "sandwich", has recently been installed in Quebec. Unfortunately, most of the R&D in adaptations for more difficult conditions and steeper angles is currently being done outside of Canada. For example, a conveyer is being installed in Yugoslavia[6] to carry crushed copper ore out of an open pit mine with an angle of incline of 35.5 degrees, more than double the current conventional conveyer design limit of 16 degrees. It will be the first unit to carry high tonnages (up to 4000 tph) at a high angle using conventional belting and components.

Canadian R&D efforts in conveyors and slurry pipelines for moving crushed rock and ore should be encouraged both at the theoretical level, such as computer simulation studies in university mine departments, and at the applied level, probably with joint ventures involving manufacturers, mining companies, and academics.

Ground Control

There is a major opportunity for advance in techniques of ground control and the associated hardware for underground mining. At present, the ground control techniques involve mainly the use of various devices and materials to minimize rock falls and scaling, and the use of sensors to predict possible rock bursts. As noted in the section on basic research of opportunities, there is need for R&D aimed at reducing or eliminating rock bursts and instability problems. There is also a need for the development of sensors, monitoring devices, and other hardware, both for the basic research studies and for monitoring of ongoing operations, in order to prevent or, as a last resort, to predict problems. Since this sort of equipment will evolve from existing geophysical and other technologies in which Canada is already active and successful, and since this is a traditional area of Canadian expertise, it seems likely that Canadian R&D, manufacturing, and commercialization in this area can be expected.

Automation and Control Equipment

This topic is discussed in more detail in chapter 4. Briefly, there is both a tremendous need and a tremendous opportunity for Canadian innovation in this line. Two major avenues need to be pursued:

6. Mining Journal, September 27, 1985, p. 252.

- government and mining industry support for multidisciplinary approaches to equipment development, such as those promoted and assisted by the Ontario technology centres or the Inco-Spar collaboration, and involving a variety of joint-venture partners to develop new products;
- research, educational, and technology transfer activities, such as those promoted by the Canadian Advanced Technology Association, to adapt existing technology to mining applications.

Manufacturers and vendors of the newly developing control technology have in general had little exposure to the mining industry. Government assistance therefore might include the sponsorship of seminars and meetings to bring the two groups together. It might also take the form of assistance to field demonstration projects, which will continue to be fairly high risk until problems of reliability and durability of the delicate electronic equipment can be solved, to make it more suitable for the rugged conditions and hostile environment encountered in mining. Technology transfer from military developments might be sought in this area.

Support Services and Equipment

Ventilation is a key area for improvement in underground mining. It adds considerably to the cost of mining, and can in fact be the chief limiting factor in the depths that be be reached in some mines. Most mine ventilation equipment is presently imported. The principal manufacturing opportunity for Canadian firms would appear to be in the area of monitoring equipment and sensors. Because ventilation is a problem common to all underground mines, and because it is a subject of vital importance to the health and safety of workers, a strong argument can be made for direct government participation in and support of R&D in the field, and for support of university studies and industrial R&D as well, both separately and as joint ventures.

Among the ventilation projects reported to CANMET's survey of mining research[7] were the following:

- Cominco - control of diesel emmissions;
- MIROC - development of a system for monitoring mine ventilation;

7. CANMET, Index of Mining Technology Projects, 1986.

- Mines Accident Prevention Association of Ontario - ventilation advisory service to Ontario mines;
- CANMET - evaluation of environmental contaminant and ventilation parameter sensors and systems for underground environmental assessment;
- CANMET - measurement of current levels of respirable dust in selected mines, and development of dust control measures;
- Laval - basic studies of mine ventilation and health aspects, and implementation of a monitoring system for a ventilation network at Brunswick;
- Queen's - ventilation studies at Denison mines to establish a computer model of the mine ventilation network.

Communication between workers and between computers and sensors and control equipment is another important area, one that is discussed in more detail in chapter 4.

Other types of support equipment, such as electrical supplies, pumps, tools, belting, pipes, hoses, clothing, cables, generators, rock bolts, concrete, motors, etc. are not unique to the mining industry, and come from a variety of sources, both domestic and imported. Technological innovation, except in isolated incidents involving on-site solutions to particular problems, will generally originate outside the mining sector and, in many cases, outside Canada. Table 38 shows CANMET's count of sources for equipment and materials certified for use in underground mines in Canada for selected categories, classified as supplied by Canadian manufacturers or supplied by multinationals, not Canadian owned.

Table 38

SOURCE OF EQUIPMENT FOR USE IN UNDERGROUND MINES

	Non Canadian	Canadian
Electrical equipment	over 100	15
Conveyor belting	20	0
Diesel equipment	9	3
Ducts and pipes	17	4
Hydraulic fluids	11	5

Source: CANMET, List of Certified Equipment and Materials for Use in Underground Mines, Canadian Explosives Laboratory, Division Report ERP/MRL 85-61 (TR), June 1985.

Equipment Related to Health, Safety, and Environmental Concerns

Governments are setting increasingly stringent standards for environmental and working conditions in the mining industry, and in some cases companies are ahead of government requirements. Since the government-imposed requirements are common to all producers, result at times in additional production costs, and frequently require technological innovations, government R&D participation and support in this field is especially appropriate.

The most significant advance for health and safety in underground mining will be removal of the worker from underground mining. Until that happens, the innovations in methods and equipment already discussed that will facilitate improved health, safety, and environmental conditions are the following:

- bulk mining
- bioleaching and chemical leaching of ores
- ground control
- communication systems
- sensors for environmental, product, and equipment monitoring
- remote control
- hoists
- personal safety gear

Personal safety equipment includes such items as clothing, boots, headgear, and lamps. However, in terms of commercialization, MIROC has found this field to be something of a loss-leader.

It should be noted that at least one underground mine has recently reported that its underground accident rate has fallen below the rate for its surface workers. In other words, the problems are not <u>all</u> underground.

Chapter 8. OPPORTUNITIES IN MINERAL PROCESSING AND GOLD METALLURGY

GOALS

Mineral processing involves transforming ore into a product that is ready for use in crude form in the case of some industrial minerals and coal, or into a metallic concentrate. In the case of gold and silver, the final product may be bullion or bars. It is a stage in the mineral production cycle that is less easily defined, in terms of goals and activities, than the mining stage, because it is even more commodity-specific than mining. For coal, for example, the process is called beneficiation, and its goal is the production of a clean usable product, with varying physical and chemical properties depending on its intended use. For iron ore, the process depends on both the nature of the ore and the type of smelter or blast furnance to which the ore is headed; the end product of ore preparation may, for example be ore itself (in the case of direct-shipping ores), concentrate, or pellets. For ore from lode gold mines, the milling stage involves a variety of approaches and methods, both physical and chemical; it usually proceeds directly to refining, and the final product is metallic gold. Where gold is a byproduct in a polymetallic mine, it is usually shipped out in concentrate with other metals, and separated at a later stage.

For most base metal ores, the goal of the milling process is to transform broken ore into a finely ground metallic concentrate which is then shipped from the mill to a facility for further processing by extractive metallurgical techniques. This chapter will look at the milling process for base metal and polymetallic ores, and at gold and iron ore processing.

Because ore is a high-bulk low-value product and therefore uneconomical to transport, mills are usually located at or close to the mines that feed them. Where mines are close together, one mill may serve a number of mines usually under common ownership. In the case of gold, there is an increasing tendency toward custom milling, where mills agree to process ore from a variety of nearby mines, even when the mines are not all owned by the same company.

There is a great disparity among commodities in terms of the disposition of the final product of the mill. Although concentrate still contains a high percent of waste material (for example, about 75 percent in the case of copper concentrates), it is often shipped great distances, both within and beyond Canada, for further processing. Table 39 indicates the percent of concentrates of specific commodities that stay in Canada for further processing, and the percent that is exported as concentrate.

Table 39

DISPOSITION OF SELECTED CANADIAN MINERAL PRODUCTS IN CONCENTRATE FORM, 1984

Commodity	Percent Shipped for Processing in Canada	Percent Exported as Concentrate
Copper	62	38
Zinc	68	32
Lead	63	37
Nickel	100	0
Molybdenum	0.4	99.6
Silver	73	27
Gold	91	9
Iron Ore	26	74
Asbestos	3	97

Source: Energy, Mines and Resources Canada, Canadian Mines: Perspective from 1985, Ottawa, 1986.

METHODS AND EQUIPMENT - THE STATE OF THE ART

Base Metal Ores

Processing of base metal ores involves transforming ore, which may contain less than 1 percent metal, to a concentrate, which may for example contain 20 percent metal. This process, called beneficiation or milling, consists of two major types of operation. The first, comminution, involves crushing and grinding, as well as sorting by size and to reject waste rock. The second, concentration, generally begins with flotation, in which the mineral foams to the surface and the tailings or rejects sink to the bottom and are removed. The mineral-rich foam is then dewatered and dried.

Comminution

Crushing and grinding of the ore is an energy intensive and inefficient process, accounting for about 50 percent of the energy used in a typical base metal mill.[1] It is estimated that less than 1 percent of the energy consumed in conventional grinding is actually used for size reduction of the material being ground (see table 41).

1. B.A. Willis, "Mineral Processing", Mining Annual Review 1985, p. 234.

In most operations, the primary crusher is a jaw crusher, generally located underground at the base of the ore chute. In the mill, further size reduction is accomplished by a variety of combinations of crushing and grinding equipment, depending on the characteristics of the ore, energy and labour costs, the preferences of the mill's owners and designers, and other factors. The ores are carried through the crushing and grinding circuit in an increasingly fine slurry or pulp of water plus oils and chemicals.

The basic comminution circuit is usually one of the following:[2]

- single stage autogenous
- single stage semi-autogenous
- primary autogenous and secondary pebble mill
- primary autogenous and secondary ball mill
- primary semi-autogenous and secondary ball mill
- cone crusher and rod mill and pebble mill
- cone crusher and rod mill and ball mill
- cone crusher and single stage ball mill
- high energy automated crushing and single stage ball mill

There have been a few significant innovations in crushing and grinding equipment over the past decades. Among the recent improvements have been:

- an increasing use of autogenous grinders;
- development of mobile crushers for both underground and open-pit mines;
- improved durability of materials used in the comminution equipment, which is exposed to severe abrasion and corrosion conditions;
- dry milling circuits, which are more economical in terms of energy use and chemicals, and have fewer environmental side effects.

Innovative approaches which have been suggested but not yet applied include preliminary heating of the ore, or the application of a combination of electric and ultrasonic energy, both of which are expected to weaken the grain boundaries and improve the energy efficiency of crushing and grinding.

2. Ibid., p. 235.

Concentration

Concentration consists of several possible stages, including separation and flotation. Separation can occur during or even before the comminution stage, as well as after it. For separation, the particles being processed are sorted by size, density, minerals present, and other characteristics, and then recycled for further size reduction, sent ahead in the processing circuit, or rejected as tailings. These sorting or separation techniques can include screening, classification, gravity concentration, and magnetic separation.

Classification is the process of separating mixtures of particles (i.e. finely ground metallic ores and tailings) into a number of streams on the basis of their relative velocities, which in turn are functions of particle size, shape, and density. The principal types of equipment used are hydrocyclones, hydraulic classifiers, and mechanical classifiers. Hydrocyclones have seen increasing use in recent years, in mineral processing as well as other fields such as chemicals, petrochemicals, power generation, and textiles. Improved materials such as "super ceramics" have enhanced their usefulness for mineral classification, increasing both resistance to abrasion and capability for very fine separation.

Gravity concentration methods declined in importance for base metals with the introduction of flotation techniques, but are being reconsidered in view of their relative simplicity, economy, and lack of environmental problems. Among the equipment used for gravity separation, still an important technique for iron ore, tin, and tungsten, are: spiral concentrators, pinched sluices, Reichert cones, shaking tables, Duplex concentrators, Bartles-Mozley concentrators, cross-belt separators, and pneumatic tables. Spiral concentrators in particular have seen design improvements in recent years.

Flotation is a technique used to separate particles of ores, principally metallic sulphide ores, from reject particles. It requires three types of chemical reagents:

- collectors or flotation reagents, which adhere selectively the sulphide particles and are hydrophobic, so they attach themselves to bubbles and float to the surface. Some minerals such as molybdenite are naturally hydrophobic in their sulphide form, and do not require collectors;
- frothing reagents, which promote the presence, the strength, and the survival of the bubbles;
- regulators - other reagants, such as depressants.

The sequence and reagents used for flotation depend on the ore being processed. For example, processes for copper-zinc and lead-zinc ores will generally float the copper or lead first. For copper-lead-zinc ores, the copper and lead may be floated together, then separated subsequently by flotation using selective depressants. For nickel-copper ores, a nickel-copper concentrate is floated, and pyrrhotite, pentlandite and chalcopyrite in the concentrate can be separated in subsequent stages. For such polymetallic ores, there is often a very complicated series of cycling and recycling stages to separate the various constituent metals using a succession of physical and chemical treatments.

The final product of flotation is a concentrate containing one or more metals which is then dewatered, dried, and sent on for extractive metallurgy. Dewatering involves the use of flocculants, chemicals which cause agglomeration of the concentrate and enhance the effectiveness of filtration methods, which may employ equipment such as filter presses, belt filters, and rotary drum filters.

Improvements in Base Metal Processing

There have not been any fundamental changes in the basic approaches to milling techniques in recent years. Innovations have tended to be incremental, providing increased size and efficiency of existing concepts and hardware. Among the equipment innovations and improvements in recent decades have been the following:[3]

- gyratory crushers;
- some attempts at preconcentration by ore sorting;
- autogenous and centrifugal grinding;
- hydrocyclones for size separation, solid-liquid separation, and heavy media concentration;
- screening by seive bends, and gravity concentration by Humphrey's spirals and Reichart cones;
- reagents for flotation of nonsulphide minerals and for selective flocculation;
- very high intensity wet and dry magnetic separators;
- high capacity thickeners, disc and belt filters, and continuous filter presses;

1. P.E. Queneau, "Innovation and the Future of the American Primary Metals Industry", Materials and Society, vol. 9, no. 2, 1985, pp. 217-229.

- instrumentation for on-line measurement of process variables;
- presorting techniques, such as selective magnetic coating by ferromagnetic material followed by high-intensity magnetic separation;
- software for simulation of process design and operations, such as CANMET's SPOC program;
- moves toward automatic process control using multiple sensors and actuators with monitoring, data storage and control, using digital computers and analog displays on a systems basis.

Areas in base metal milling most in need of improvement, and to be discussed further below in terms of the opportunities for innovation that they present, include:

- fundamental rethinking and simplification of the milling process, which has grown in a piecemeal and ad hoc fashion;
- new approaches to or bypassing of the grinding circuit, to reduce energy costs;
- additional presorting of ore and waste;
- increased use of rock-on-rock or autogenous grinding to reduce consumption of steel and other materials;
- increased use of control techniques and automation;
- improved recoveries of metals presently lost in tailings.

Processing Gold Ores

The cyanide process for recovering gold from ore was patented in the 19th century and has seen little fundamental change since that time. It can efficiently transform gold ores containing as little as 0.1 percent or less to a precipitate which can be refined directly to bullion, with a loss of only a few percent of the contained gold. Essentially, the process requires crushing and grinding of the ore to expose gold surfaces, and treatment of the ore by a weak solution of alkaline cyanide. If the ore contains arsenic, it must be roasted before cyanidation. The cyanide preferentially dissolves out the gold, as well as some other minerals including silver, copper, and some zinc, iron and nickel minerals. After impurities are removed from the pregnant solution, it is deaerated and treated with zinc dust, which causes the gold, silver and zinc to precipitate out, along with any traces of iron and copper that may remain. Sulphuric acid is then used to remove the copper, iron and zinc. The remaining precipitate is then smelted to remove any trace impurities that may remain, and to separate the gold from the silver. The liquid re-

agents are recirculated, but solid wastes or tailings must be treated to prevent environmental damage by any contained cyanide.

With the rise in gold prices following the early 1970s, additions to the cyanidation process as well as new methods of processing gold have been investigated and adopted, with a view to increased recoveries and to exploiting low-grade deposits. Among the innovations are the following:

- addition of and improvements in flotation procedures in the gold milling cycle;
- introduction of the carbon-in-pulp (CIP) adsorption process, and recent significant reductions in contact time required for its operation (e.g. from the standard 8 hours to a few minutes, according to some reports from South Africa);
- introduction of heap leaching, for low-cost processing of low-grade gold ores, and even of wastes and tailings. First introduced in the U.S. southwest, with more recent adaptations to the colder Canadian climatic conditions, the technique has been described as a revolution in gold processing, one that has permitted exploitation of a rapidly-expanding number of orebodies that were previously uneconomic;
- introduction of tank leaching, which provides greater control of process conditions;
- introduction of bioleaching for some types of gold ores;
- several improved methods of cyanide recovery, such as those developed in Canada by Inco, and by CANMET and Witteck Development Inc.;
- introduction of other chemicals such as thiourea to replace cyanide as a leaching agent, reduce environmental problems, reduce capital costs, and improve the kinetics (rate of reaction) of the leaching process, with reductions from 90 hours to 3 or 4 hours reported;
- application of pressure oxidation to improve gold extraction from refractory ores.

Research in gold processing techniques and innovations in methods and equipment are pursued most strongly by the leading gold producer, South Africa, where the Chamber of Mines reinvests impressive amounts of revenues from gold mining into R&D. The research is very directed and applied, and is assisted by the fact that, in addition to having large quantities of gold, the ores in South Africa are less complex than in Canada. The Soviet Union is also a source of innovations in methods, although there is much less communication and exchange of information than with South Africa.

Iron Ore Processing

Iron ore, unlike gold and most base metal ores, has a fairly high mineral content in its crude ore form. It is reduced in size by crushing and grinding, usually using autogenous and rod mills. The iron-bearing particles are separated from the waste by a variety of techniques and equipment such as spirals, magnetic separation, and heavy media separation (sink-float process).

Iron ore is a raw material for the steel-making business, and Canadian ore is shipped in three forms:

- concentrates
- agglomerates (concentrates which have been sintered or pelletized)
- direct shipping ores

Direct shipping ores are particularly attractive to producers, because they skip the processing stages and associated costs. Unfortunately, Canada has little ore suitable for direct shipping, and processed pellets and concentrates constitute the bulk of Canadian iron ore shipments. In North America, Canada's major market, pellets have the largest market share.

A major need for Canadian iron ore producers in terms of processing technology is the flexibility to respond to changes in feedstock requirements dictated by changing steel-making technology. Foremost, however, is the need to keep costs down in order to compete with growing low-cost production from the Third World.

INNOVATION OPPORTUNITIES IN PROCESSING

Introduction

Opportunities to introduce technological innovations into processing operations can arise from two sources: the opening up of new facilities, and the upgrading or expansion of existing facilities. Due to over-capacity in mineral production facilities world-wide, it appears that there will be relatively few new processing facilities opened up in Canada in the foreseeable future, beyond the establishment of mills for new gold mines. Consequently, refits of existing operations will be of major interest.

Of the close to 130 milling facilities operating in Canada in 1984, only 25 percent had been built or expanded since 1980. A significant proportion of these newer mills are gold mills associated with new gold

mines. Gold mines also accounted for the oldest mills still in operation, with two dating from 1912. Fully 36 percent of the mills were built before 1965, and more than half of these predated 1945. It is clear, therefore, that the mineral processing sector includes a significant number of facilities that have seen only incremental improvement over the years, and are candidates for technological upgrading.

Three major factors will be acting as constraints to major refitting and innovation, however. One is the cash-poor position of many producers, which forces them to pursue productivity improvement by, among other things, foregoing capital improvements. A second is that many of the older mills are associated with mines that are approaching depletion, and refitting cannot be justified for the remaining mine life. A third is that many of the mills are very small, with small work forces, and would achieve little advantage in reduced operating costs through, for example, the introduction of an automated process. Table 40 shows the size distribution of mills associated with metal mines in Canada in 1984.

For the larger base metal and iron ore processing plants, automation will certainly offer significantly reduced operating costs, as will improvements in or, better still, elimination of the costly and energy-inefficient crushing and grinding circuits. For smaller plants, particularly gold mills, innovations in the area of enhanced recovery and improved environmental protection will be particularly attractive. In this vein, it is interesting to note that, in 1983 in the course of expansion and modernizing of its 1912 mill, Dome Mines recovered over 37,000 ounces of gold from the old building and equipment, which represented an extraordinary income of almost $20 million at 1983 gold prices.

Table 40

SIZE OF PROCESSING PLANTS ASSOCIATED WITH METAL MINES, BY MAJOR METAL, 1984
(tonnes per day mill capacity)

	Under 2,000	2,000-10,000	10,000-100,000	Over 100,000
Base metal and polymetallic	20	29	16	0
Gold and silver	37	4	0	0
Iron ore	0	0	3	8
Uranium	3	3	1	0
Other	2	1		

Source: adapted from EMR, Mining and Mineral Processing Operations in Canada, 1984.

Basic Research

Individuals in the mineral processing field generally seem to agree that the vast majority of the technological innovations that should be or will be introduced into mineral processing in the next decade or so will arise from technology that is already known, but that needs to be transferred into the industry from other applications and adapted for processing needs.

Nevertheless, it appears that there are several areas of basic research that will benefit this area:

in biology
- studies of biological leaching agents and reaction parameters;

in chemistry and chemical engineering
- surface chemistry
- studies of chemical leaching agents and reaction kinetics
- studies related to selectively and activity of chemical reagents;

in mineralogy
- studies of properties of minerals and their compounds, particularly with relation to breaking down of grain boundaries;

in physics
- studies that will contribute to the development of sensing and measuring devices, as well as studies of properties of materials.

Processing Methods

Mineral processors in industry are caught between two activities, mining, and smelting and refining, each of which exerts pressures on the mill operator, in terms of quantity and quality requirements related to both the feed provided and the product required. Given these pressures, and cost constraints, processors have little opportunity for fundamental re-thinking of the processes they apply, and how they might be redesigned rather than patched up and improved incrementally.

Applied research into novel approaches to processing methods will be long-term and costly, and will require communication across sectors and disciplines. It seems therefore to call for joint ventures, with shared industry-government funding, and access to operating mines and mills for university researchers, since laboratories will not permit the scale of work needed in many aspects of the research and development and demonstration. As in research in mining methods, funding support will be required to see a project through, assuming its progress justifies continuation, from the basic conception to the demonstration stage.

One factor that should be kept in mind in such applied studies is the present level of energy consumption in the comminution stage, which accounts for about 50 percent of processing costs. Table 41 indicates the energy losses presently encountered in a standard ball mill. It seems clear that fundamental rethinking of the process of size reduction could lead to significant improvement in energy efficiency. One approach is the use of leaching techniques, which will be discussed in more detail under hydrometallurgy, in the next section. However, for the foreseeable future, a wide range of minerals will not be amenable to leaching methods, and for these, mainly base metals and iron ore, improvements in grinding and crushing equipment and techniques will be the only answer.

Table 41

ENERGY ABSORBED IN A BALL MILL

Energy Taken by Component	Percent of Applied Energy
Bolt friction	4.3
Gear losses	8.0
Heat losses from drum	6.4
Heat absorbed by circulating air	32.0
Heat absorbed by product reduction	48.6
Theoretical energy remaining for size reduction	**0.7**

Source: "Comminution", Mining Annual Review, 1985, p. 235.

Equipment

As in mining, much of the equipment and machinery used in milling is imported. It seems likely therefore major equipment innovation will be imported as well. Areas of special opportunity for Canadian participation in techological innovation may be in the following areas.

Presorting Instrumentation

A variety of techniques presently known but not widely used in processing could be adapted for sorting of crushed ore before and during the comminution stage. These include the whole range of sensors of the sorts that will be required for automation and control functions throughout the mineral production cycle, such as infrared, X-ray, magnetic, etc. Equipment companies presently engaged in manufacturing geophysical instru-

ments, sensors, and measuring devices might be logical partners in joint ventures to apply their techniques to ore sorting.

Reagents

The milling phase requires a large variety and volume of reagents, such as lime, cyanide, collectors, frothers, flocculants, and a variety of others including copper sulphate, zinc sulphate and zinc dust, sulphuric acid, and soda ash.

Two opportunities arise here. One is for applied research into improving the activity and selectivity of reagents; for example: selective collectors and depressants, collectors for the flotation of nonsulphide ores, selective flocculants, or flocculants for the concentration of sulphide slimes. It seems that such research would likely be of a proprietary nature and might not lend itself to widely-based joint ventures as readily as some. However, joint ventures between individual mining companies and chemical companies might be effective, or between companies and university researchers. The first opportunity leads logically to the second, which would be increased Canadian sourcing of reagents.

Gold Processing Equipment

Although South Africa is the leader in technological innovation in gold processing, there are opportunities for Canadian participation in technological innovation in methods, equipment, reagents, etc.

Gold mills tend to be relatively small; 37 of the 41 gold mills operating in 1984 were under 2000 tpd in capacity (see table 40). Gold mining is one of the few areas of the mineral sector that is expanding in Canada, offering the prospect of a number of orders for new mills in the near future. Furthermore, a large number of gold mills are very old, and may be candidates for replacement, if the economics of their deposits warrant such expenditures. It would seem, therefore, that Canadian equipment manufacturers might be in a better position to compete for orders for gold mills than, say, for base metal or coal processing plants, which will be few and far between, and will be much larger.

In addition to these market factors, Canada has an advantage in gold milling technology because it is among the leaders in several projects involving innovative approaches to gold processing, including heap leaching under cold conditions, tank leaching, bioleaching technology, and cyanide recovery.

There appears to be a need for greater communication among gold producers about the state of the art in gold processing technology. Some form of broad producer organization like the South African Chamber of Mines might be of assistance in promoting and coordinating joint research for Canadian producers as a whole. Failing that, joint ventures in projects such as shared mills, making a point of seeking out the best technology, would be an improvement, and could involve Canadian suppliers and manufacturers.

Specific areas in need of further improvement for gold processing include:

- more effective and economical methods for controlling cyanide contamination;
- methods that avoid the use of cyanide altogether (California for example is aiming at regulations prohibiting the use of cyanide);
- improvements in chemical and biological leaching techniques for use in Canada's cold climate;
- increased efficiency of leaching processes.

Automation and Control

"Automatic control of machines and unit operations (in milling) is in veriest infancy... All ore dressing operations in the larger mills are going to be on instrument control within a very few years."[4] Unfortunately, this quote from Professor Taggart of Columbia dates back about 40 years, and his vision has still not been realized. Although a few of the newer and larger mills in Canada have the look of automation, in fact none are fully automated. Monitoring systems that have been installed still require operator observation and response.

For example, one of the newest mills just opened in Canada is described "almost fully automated" in a recent article.[5] The mill produces copper, lead and zinc concentrates, and has a capacity of 3000 tpd, using conventional ball and rod mills, Outokompu flotation cells, and Larox filters. Although still operator-controlled, however, the mill has installed a 17-stream on-stream analyzer which, it is hoped, will eventually be tied into an automatic process controller.

Significant opportunities for Canadian-developed innovations exist in the area of automation and process control, particularly in developing new

4. Quoted in P.E. Queneau, op. cit.
5. Northern Miner, 30 September 1985.

sensors or adapting existing sensing and monitoring devices, and in developing applications software for process design and control.

Rethinking of the whole mineral processing circuit, with a view to optimization and simplification of operations, as well as to cost and pollution reductions, will greatly enhance the value of automation of processing. Unfortunately, this is a luxury few operating companies can afford. Furthermore, before optimum redesign of operations can be achieved, a great deal of long-term applied and basic research will be needed to unlock the mysteries of many of the physical processes and chemical reactions involved in ore size reduction, and in isolation and separation of metal particles.

Chapter 9. OPPORTUNITIES IN EXTRACTIVE OR PROCESS METALLURGY[1]

INTRODUCTION

Metallurgical operations have been the focus of much of the technological development effort in the mineral industry in the past, and many of the basic problems have been solved. In almost all the base metals, high-recovery energy-efficient smelting and refining processes now exist, although there is still significant room for improvement, as demonstrated by the Noranda process, which more than doubled capacity by the introduction of oxygen. Unfortunately, there is a prevalent mood in the metallurgical sector that the limits of existing process performance characteristics are now being approached in recently constructed facilities. Nevertheless, major breakthroughs can still be expected in future from the application of new technologies, such as bio- and hydrometallurgical treatment of concentrates. Management and researchers must be open to innovation, if these opportunities are to be realized.

The challenge facing the Canadian metallurgical industry in the forseeable future is to keep its existing plants competitive with others in the world without having to resort to massive capital spending programs which the industry cannot afford. In most metals, wherever facilities are built in the near future, they will most likely employ current state-of-the-art processes incorporating the latest incremental improvements.

While the industry continues to maintain extensive pyrometallurgical and hydrometallurgical development programs, these are now focused more on incremental improvements to existing processes than the development of radical new technologies. In addition, more emphasis is being placed on the application of peripheral technologies in metallurgical operations to improve the performance of the existing core technologies. However, work in these areas, such as computer process control, is constrained by a shortage of appropriately qualified personnel in the industry and by shortcomings in the basic understanding of the chemistry and physics underlying the whole process of transition from concentrate to metal.

There are few cooperative industry research and development activities in the metallurgical area; most of the integrated companies maintain their own separate R&D facilities and staff. As a result, most of the private sector work is developmental, with CANMET playing a supporting

1. For further information on this subject, see also Minerals, Metals and Mining Technology (Ottawa: EMR/CANMET, 1984).

research role. Research is also performed in Canadian universities on a fairly widespread basis, although the actual dollar level of support appears to be low.

Since commodity-specific distinctions are particularly important in this chapter, we will first review the metallurgical processes by major metal: copper, nickel, zinc, lead and aluminum.

COPPER

Copper Smelting

Copper smelting is an international business, in which Canada occupies a significant position with about 7 percent of western world capacity. Canadian smelters not only treat concentrates from integrated mining operations, but also compete for custom concentrates, domestically and internationally.

There are 7 copper smelters in Canada with a total capacity in 1984 of 635,000 tonnes per year. They employ a variety of pyrometallurgical technologies. These range from the traditional batch reverberatory furnaces, employed in the older smelters, to the continuous Mitsubishi process installed at the Kidd Creek metallurgical site. Afton Mines, a subsidiary of Teck Corporation, was the site of the first commercial application of a top-blown rotary converter (TBRC) for copper.

Several facilities, including Noranda's Horne and Gaspe smelters, and the Hudson Bay facility at Flin Flon, treat custom materials. These are older facilities carrying low depreciation charges, which have been continually updated technologically, although sulphur dioxide emissions remain a serious concern at the Horne and Flin Flon.

Canada's integrated mining companies have a strong tradition of pyrometallurgical innovation and have developed a number of major advances in copper smelting including the Inco flash furnace which was commercialized in 1952, and the Noranda continuous reactor which was commercialized in 1973. At the present time, however, the reduction in spending on research and development has led to the virtual cessation of any significant work on major new copper smelting processes in Canada's integrated producers.

New copper smelting processes have been the focus of significant development efforts during the last 25 years. These have taken place in a variety of countries, but predominantly Canada, Japan and Finland. As a result, new smelters can be built from a variety of alternative technologies, each with similar performance characteristics, including high recoveries and gas emission containment performance.

While a number of additional new smelting processes have been tried on a laboratory scale in recent years, none have been promising enough to move forward to commercial piloting. The development of major new processes, such as a truly continuous copper smelter, are not considered a high priority by the industry, since it is unlikely that either a significant competitive advantage could be gained, or that major new copper smelters will be built in Canada in the forseeable future to use these new technologies.

The major technical challenges facing Canadian copper smelters in the forseeable future are, then:

- containment of sulphur dioxide emissions (older facilities only);
- reduced energy consumption;
- improved minor element removal;
- better process optimization through control systems;
- reduced labour requirements through automation;
- increased productivity in converting operations through continuous operations.

These will be reviewed below by specific smelting technology, and then briefly by adjacent technologies, such as converting, casting, and process control.

Continuous Smelters

Continuous smelting processes are likely to be dominant in the future, as they offer significant technical and economic advantages over batch facilities. Two "continuous" smelting processes are presently operating in Canada: the Noranda continuous reactor, which although it has the potential to be a one-vessel continuous process is not operated in that mode; and the Mitsubishi continuous process which is a three-vessel continuous operation.

The Noranda continuous reactor was developed by Noranda Inc. and retrofitted into the existing Horne facility where it is now the main smelting unit. Its high recoveries and other characteristics make it ideal for custom smelting applications. In addition, it could be constructed economically in relatively low-capacity configurations in a mode of operation similar to steel mini-mills.

As operated, the reactor is not a truly continuous process. However, a high-strength gas stream is produced which is amenable to transformation into sulphuric acid. A high grade matte is produced by the

reactor which is then transfered to batch converters for transforming into blister copper. These converters produce low-concentration off-gas streams which cannot be economically captured to produce acid.

The Noranda continuous reactor could benefit from significant development work to permit its operation as a one-stage smelting vessel, although a number of technical problems would have to be overcome. These include removal of minor element impurities, such as bismuth and antimony, as well as refractory life constraints which lead to a short campaign life in this mode of operation. Work has been carried out in this direction at the Noranda Research Centre, but no major efforts are currently under way.

Only one Mitsubishi continuous smelter operates in Canada, at the metallurgical site of Kidd Creek Mines Limited, in Timmins. This technology was commercialized in Japan in 1974, and has excellent sulphur dioxide containment characteristics. The technology was purchased from Mitsubishi under license, and reciprocal technology transfer agreements exist. Kidd Creek operates the smelter generally in line with practices and procedures established by Mitsubishi.

Major development of this technology is not contemplated in Canada. However, a number of technological improvements are possible which would make the smelter more competitive in the future. The first area of concern is improved handling of minor element impurities which would facilitate custom operations at some future date. A second area of opportunity is improved energy efficiency.

Reverberatory Smelters

This is the oldest smelting technology employed in Canada today, being used in the Gaspe, Horne and Hudson Bay facilities. A low-grade copper matte is produced in these smelters which is then transferred to batch converters for transforming into blister copper by blowing air through the metal bath to remove additional impurities.

Compared to modern flash and continuous smelting processes, reverbs are energy- and labour-intensive, since most were built over 30 years ago. Working environments associated with these operations are also poor compared to those in modern processes. In addition, the technology is not amenable to sulphur dioxide containment because the gas streams are too dilute and variable for economic capture of the gas and conversion to sulphuric acid.

Work has been carried out by Noranda Inc. and in the United States on methods of using oxygen enrichment to increase energy efficiency and

also produce stronger gas streams which may be rich enough in sulphur dioxide to convert economically to sulphuric acid. However, with the exception of the Gaspe smelter, the age of the reverberatory smelters in Canada and the limited supply of concentrates for them suggest that upgrading costs will be prohibitive, and that they will be shut, rather than converted.

The Gaspe smelter has an advantageous location with respect to imported custom concentrates, and a continuing captive source of concentrate from its associated mining operation. At present, a fluid bed roaster is used prior to smelting; it drives off 40 percent of the sulphur into a high strength gas stream which is then converted to sulphuric acid.

Flash Smelters

The dominant copper smelting technology used in the industry is the flash process developed by Outokumpu of Finland. Over 25 of these smelters are presently in operation, and Outokumpu maintains an extensive development program to support the technology. A key element in this program is the technical feedback it obtains from, and shares with, users on operating and technical performance and improvements. The process is relatively energy efficient, has good recoveries, and produces an acceptably high-strength gas stream suitable for acid production.

No Outokumpu flash smelters are installed in Canada. Inco has developed and installed its own process in Sudbury, where a second-generation unit has operated since 1968. A very high-strength sulphur dioxide gas stream is produced by the process which can be economically recovered and sold in liquid form. The process is also exceptionally energy efficient.

The technology of flash smelting is already well developed, and it probably represents the ultimate extension of batch pyrometallurgical processes. The draw-back to the technology is the constraint imposed by the heat balance, which dictates the matte grade that can be produced, and thereby the amount of converting that has to be done outside the smelting unit. At the present time, it appears doubtful that further development of flash smelting can result in a single stage process which can produce copper directly, except on exceptionally clean concentrates with few minor element impurities.

Converter Technology

In the medium-term, development of an economical continuous converter technology has been identified as one of the most important technical advances to be achieved. Of special interest would be one that could be retrofitted into existing converter operations through modifications of vessels already in operation.

Development of this technology would be applicable to most of the smelters currently in operation (the Mitsubishi continuous process being the most notable exception), since nearly all require conversion of a high grade matte. The characteristics of the continuous converter would be acceptable elimination of minor elements, together with the production of a high strength sulphur dioxide gas stream. Researchers at Noranda Inc. have been proposing this type of development for some years, but the company has been unsuccessful in attracting a joint-venture partner for what would be a costly development.

Process Control Opportunities

Opportunities exist for considerable up-grading of process control in smelters, especially in the flash technology where metal residence time is short. At present, computer monitoring of process parameters is fairly widespread, but closed loop control is not widely practiced. To make this possible, considerable improvement will have to take place in the basic understanding of some of the scientific fundamentals of these processes to permit instrumentation and control technologies to be developed.

New computer technologies, either hardware or software, are not likely to be required, for this development to take place. The major barriers in this area at the present time are the lack of fundamental process understanding and a shortage of appropriately qualified personnel in the research and operating groups of the integrated mining companies.

Opportunities for Peripheral Technologies

There are considerable opportunities in smelters for technological improvement through automation, especially those that are older and labour intensive. Continuous anode casting, and mechanized handling systems, already adopted in some smelters, need to be transferred through the industry, and improvements are possible. The technology for these developments almost certainly exists elsewhere already, and only needs to be modified and applied.

Smelters are also possible sites for future application of robots, especially in hazardous and strenuous working conditions. Although this technology is not yet sufficiently developed for specific application, opportunities to use robots in furance work or materials handling have been identified.

Copper Refining

Canada possesses three copper refineries: Noranda's CCR division in East Montreal, Inco's Copper Cliff refinery, and the Kidd Creek refinery at Timmins. The first two are older operations, but the Kidd Creek is relatively new, and uses the latest tank house technology, purchased from Mitsubishi in Japan. Falconbridge Limited operates a nickel/copper refinery in Norway.

The basic approach to copper refining has changed relatively little in recent decades, although automation has considerably reduced labour requirements, and current densities and efficiency have been increased. Some researchers argue that refining, which remains a batch process, offers considerable opportunity for radical technological change through the development of a continuous refining process. Some exploratory research on alternative approaches has already been undertaken in two of the integrated companies.

At the present time, however, a number of technical challenges face Canadian refineries if they are to remain among the world's leading producers. Possibly the most important of these challenges is to produce premium-quality copper to the customers' specifications. Minor element impurities in copper cathodes can prevent them from being classed as premium grade, which is receiving increasing acceptance as the standard in a number of applications. Refineries treating custom materials, and those with concentrates containing high levels of minor elements, are actively researching improved levels of minor element elimination through techniques such as electrolyte purification. Those that have premium products are able to command premium prices.

A second major technical challenge for Canadian refineries is to increase the recovery of byproducts, such as precious metals, selenium, and columbium from the insoluble slimes. Although some Canadian refiners now have excellent byproduct recoveries, European custom refineries have established a technological lead in this area. While their technologies can be purchased, they are likely to be expensive and require modification for application in Canadian facilities.

Canada's older refineries also face automation opportunities similar to those in smelting, to reduce labour requirements while at the same time ensuring a high quality product. Technologies already to exist to mechanize starting-sheet preparation, dipping, and stripping, but these may have to be modified to be applied in these older facilities.

Hydrometallurgical Processes

A variety of hydrometallurgical processes for extracting copper from concentrates have been proposed, but none are currently operational in Canada on a commercial scale. The major processes which have been examined include:

- the S-C copper process developed and piloted by Sherritt Gordon Mines and Cominco Limited;
- Anaconda's Arbiter process, which appears to have high energy and reagent costs;
- the CLEAR process, developed and commercialized in the USA by Duval Corp.

Very little work in this area is being undertaken in Canada at the present time, but there are indications that work is being carried out elsewhere in the United States and Europe which, if successful, could lead to significant cost reductions in the later stages of processing.

NICKEL

There are three nickel smelters and three refineries in Canada. Inco operates integrated smelters and refineries at Copper Cliff in Sudbury and Thompson, Manitoba. Falconbridge Limited operates a copper/nickel smelter in Ontario, and ships matte to its refinery in Norway. Sherritt Gordon Mines operates a custom hydrometallurgical refinery in Fort Saskatchewan. Each of these processes (with the exception of Inco's Thompson smelter and the Falconbridge smelter in Ontario) is essentially unique, and each faces somewhat different technical challenges.

Both Falconbridge and Inco also operate lateritic nickel mines overseas, for which they provide technical support. As there are no ore deposits and operations of this type in Canada, these activities will not be dealt with in this report.

Nickel Smelting

Two types of nickel smelter technology are currently employed in Canada. These are the traditional reverberatory furnace type of operation, which has similar drawbacks to those in copper, and the more modern electric furnace technology producing a high grade matte.

At Copper Cliff, Inco maintains a traditional multi-hearth roaster/reverberatory furnace/batch converting operation treating a 10-percent nickel/2-percent copper concentrate to produce a 50-percent nickel/26-percent copper matte which is then slow-cooled and separated into three different concentrate streams. One of these, a metallics concentrate, is sent to the Copper Cliff refinery for processing. A nickel concentrate is roasted in fluid bed roasters to produce nickel oxide for direct sale or further refining.

As with copper reverberatory furnaces, the major technical challenges at the Copper Cliff smelter are related to sulphur dioxide emission control and energy efficiency. Weak gas streams from the roasters and reverberatory furnace, and variable converter emissions do not permit economic recovery and conversion of sulphur dioxide with existing technologies. All the sulphur dioxide presently produced is emitted to the atmosphere. It is unlikely that new emission control technology can be retrofitted on the existing plant.

Inco's Thompson nickel smelter was built in 1961, and employs fluid bed roasters to treat the concentrates which are then smelter in an electric furnace to produce a 25-percent nickel matte. This matte is then upgraded in conventional batch converters to produce a 75 to 80-percent copper nickel matte which is then sent to the refinery. The Falconbridge nickel smelter was modernized in 1978 using an updated version of the same technology.

The fluid bed roasters and electric furnaces are considerably more energy and labour efficient than the reverberatory furnace, although the batch converters continue to pose a problem with emissions. The fluid bed roasters permit 50 percent of the sulphur dioxide to be removed in a continuous stream, suitable for economic conversion to sulphuric acid. However, because of transportation costs for sulphuric acid, the gas at Thompson is emitted to the atmosphere.

No other nickel smelting processes are used in Canadian operations. However, Outokumpu flash furnaces are used abroad for treating nickel concentrates, in which up to 80 percent of the sulphur in the concentrate can be removed in a continuous, high-strength stream and liquified. A continuous smelting technology, the WORCRA process (similar to Noranda's continuous copper reactor) has been piloted but not applied commercially.

Inco is currently carrying out smelting research and development on to minimize sulphur dioxide emissions and meet control legislation. A variety of alternatives are being considered including:

- a new continuous smelting/converting process capable of producing a high strength gas stream and minimizing fuel requirements;
- a new roaster/electric furnace process which can remove up to 80 percent of the sulphur dioxide in a high strength gas stream from the roasters. Metal losses pose a problem with the process;
- application of the Inco flash furnace technology to nickel to produce a low-grade matte and a very high-strength sulphur dioxide gas stream which can be liquified.

Other development work currently underway or contemplated in nickel smelting is largely incremental, aimed at improving energy efficiency or reducing labour requirements. Slag cleaning has recently received considerable attention. As with copper, the development of a continuous converting process which can be retrofitted into existing facilities is seen as desirable, but is not currently being worked on.

Nickel Refining

Nickel matte is normally refined by a combinaton of pyro- and hydrometallurgical processing steps. Inco uses quite different refining technologies at its Copper Cliff and Thompson refineries. Copper Cliff uses a carbonyl process to produce high purity nickel pellets and powders. By-products are recovered from the carbonyl plant residues. At Thompson, a more conventional chloride-sulphate electro-refining process is employed, producing conventional cathodes. At Falconbridge's Norwegian refinery, a chlorine leach process is used to remove nickel and cobalt from matte, followed by electrowinning of these metals from solution. By-products are recovered in separate processes.

In all three refineries, technical development work is under way or contemplated to permit additional byproduct recoveries, such as selenium and chromium which are seen as major opportunities to create more value. In addition, incremental opportunities for automation and process control are continually being developed.

Falconbridge exports its nickel concentrate to its recently expanded refinery in Norway. However, the Ontario government remission order permitting export of this concentrate expires in 1990, and the company has been studying the economic and technical feasibility of locating a

nickel refinery in Canada. Early indications were that it would employ an up-dated version of one of the existing major processes, most likely Falconbridge's own chlorine leach incorporating its recent chlorine leach autoclave development. No new refining technologies are being developed as part of this study.

Hydrometallurgical Processes for Nickel

Some types of nickel concentrate can be treated by hydrometallurgical methods alone, under special circumstances. Unfortunately, all of the current leaching methods have serious deficiencies which preclude their adoption in Canada in their present state of development.

Sherritt Gordon put its ammonia leach process into production in its Fort Saskatchewan refinery in 1954. Nickel is recovered as a powder, sulphur in the form of ammonium sulphate which is sold as a fertilizer, and copper and cobalt as byproducts. The process has low recoveries of cobalt and precious metals, including the platinum group, all of which are important revenue producers from Sudbury ores. Up to the present, it has not been adopted by other Canadian producers.

Two other leach processes have also been piloted: the Sumitomo pressure leach, and the Freeport nickel pressure leach. Both these processes can only be applied to matte, and are therefore only substitutes for the refining stage. In addition, no saleable sulphur byproduct is produced. This fact, combined with precious metal recovery and iron removal problems, is likely to preclude their adoption for treating Sudbury's sulphide ores.

Only Sherrit Gordon continues to carry out significant development work in this area in Canada. Although some laboratory work on hydrometallurgical processes is being carried out by the other producers in Canada, no major processes developments are being piloted or planned.

ZINC SMELTING AND REFINING

A considerable amount of work is under way in Canada to develop new zinc treatment processes for bulk concentrates which contain lead and zinc with accompanying minor amounts of copper and precious metals. Such concentrates are typical of those from the complex lead-zinc deposits found in New Brunswick. These technical developments are likely to be among the first of the major new metallurgical processes to be commercialized when new capacity is required.

At present, four combined zinc smelter/refineries operate in Canada, treating approximately 40 percent of domestically produced zinc in concentrate. All four use conventional roast/leach/electrowin processes. Three have acid plants; the exception is at Flin Flon, which does not have an acid plant because of weak off-gas strength and remote location from acid markets. Existing zinc plants do not suffer from the same sulphur dioxide emission problems as nickel and copper smelters because the majority of the sulphur can be removed in a fluid bed roaster in a 10-percent sulphur dioxide gas stream and converted to sulphuric acid.

A major technical problem in conventional plants is the low recovery of byproducts, especially silver which is often found in Canadian lead-zinc deposits. Major programs have been under way for some years in CANMET and by the zinc producers to develop processes for improving these recoveries. Electrolyte purification is also the subject of development efforts. Other technical problems in existing zinc plants focus around incremental technical improvements to improve process efficiency, reduce labour through automation of materials handling and casting operations, and reduce energy consumption. Some incremental improvements in sulphur dioxide emissions are also possible from improved treatment of tail gases.

There is general agreement that future zinc plants in Canada will not use this old technology. Instead, new hydrometallurgical processes will be adopted which are extremely labour efficient, have excellent metal recoveries, and offer no environmental problems. Cominco Ltd. is operating the world's first hydrometallurgical leach plant at its Trail operations, and a second plant has been constructed for Kidd Creek Mines.

The new Sherritt-Cominco pressure leach process employed by Cominco at its Trail operations eliminates the traditional roasting and leaching stages, and in so doing reduces capital and operating costs. Elemental sulphur can be recovered from leach residues. High purity zinc is produced by electrolysis of the leach solutions. This technology can be retrofitted into existing plants. However, further technical development is necessary to improve recoveries of byproducts associated with this process also, especially silver.

Much of Canada's zinc production is in the form of bulk concentrates, which at present can be treated commercially only by the Imperial Smelting Process. Although there are 13 such plants in the world, none operate in Canada. This technology, however, is not adequate to meet current environmental standards and required metal recoveries, and development work is not likely to solve these problems.

Hydrometallurgical technologies are being developed as an alternative to the Imperial Smelting Process. Two of the most important of these are

being developed in Canada. The New Brunswick Research and Productivity Council is developing a sulphation roast leach process (SRL), and Sherritt Gordon is developing modified pressure sulphuric acid process (MPSA). Both offer the potential of high recoveries, low operating costs, and no significant environmental problems. Both processes have been piloted but not developed commercially.

More development work and economic evaluation is required on both these processes. Additional work is needed on improving precious metal recoveries from both processes, and on improving sulphur recovery from the MPSA process. For adoption to occur, commercial demonstrations of the technology will have to take place, which will be costly, and may involve significant technical risk which private sector firms may be unwilling or unable to assume totally.

LEAD SMELTING AND REFINING

Two lead smelter/refineries operate in Canada. Cominco operates a facility at Trail, and Brunswick Mining and Smelting has a plant in Belledune, New Brunswick. Both use Imperial sinter/blast furnaces, which produce a medium-strength sulphur dioxide gas stream which can be converted to sulphuric acid in an acid plant. At Trail, the smelter product is purified in a conventional electrolytic refinery from which high-purity lead and byproducts are recovered. Brunswick uses thermal refining and separation techniques.

Given the low price and demand for lead, very little development work is currently under way in Canada on new processes. Most of the process development taking place is incremental, aimed at improving the efficiency of existing operations through better energy use, automation and improved recoveries.

Alternative new smelting processes for lead have been developed and demonstrated abroad in recent years:

- the QSL process, which uses a single Noranda-type reactor, and has been selected for Cominco's new Trail facility;
- the KIVCET process, employing a flash furnace and an electric slag cleaning furnace;
- the Outokumpu flash furnace.

Each of these processes has high recoveries of lead, good gas handling characteristics, and relatively good economics. Further development work is under way to optimize each technology, and integrate them with downstream refining processes.

Work has taken place in the United States on a hydrometallurgical ferric chloride leach process for lead. The process has been demonstrated on a laboratory scale, but considerable more research and development work would be needed to bring the process up to commercial standards.

As a result of these developments, and the state of the lead market, it is generally considered that the development of additional new lead treatment processes is unnecessary.

ALUMINUM

Alcan, the world's major aluminum producer, maintains an extensive product and process research and development program in Canada in addition to that in its foreign research centres and foreign affiliates. As noted previously, Alcan's research effort dwarfs that of the rest of the Canadian mineral industry.

In the process area, Alcan's activities cover raw materials, alumina production, reduction, primary metal fabrication and secondary fabrication. Major opportunities for process innovation are perceived in all areas, and strategic design and demonstration programs are under way in a number of key technologies. The major objectives of Alcan's process innovation activities are:

- reduced energy requirements;
- reduced unit costs;
- improved product performance characteristics;
- new applications for aluminum from the development of new fabrication technologies.

A variety of programs are under way in support of reduced energy requirements. A new reduction cell technology, the Alcan 275 smelting technology, has been developed and demonstrated in a pilot engineering centre and is under consideration for the postponed Latherriere smelter. Additional incremental programs are also being undertaken.

Efforts to reduce unit costs and improve product performance characteristics have resulted in the development of improved metal purification technologies and the development of the commercial prototype for a continuous casting machine, capable of producing high quality re-roll stock. Further refinement of these technologies are expected in the future.

Development of technologies for the improved recycling of aluminum are also required. Alcan has already pioneered one breakthrough tech-

nology in this area: a decoating plant which removes paint and lacquer from recycled cans before they are remelted, creating a better working environment and a more efficient process. Further development of recycling technology is required, however.

Alcan is also focusing on the development of new fabrication technologies to create new markets for aluminum to offset the effects of substitution in Alcan's traditional markets. This work includes new fabrication techniques for aluminum automobile bodies, and new processes for heat exchanger manufacture, such as its NOCOLOK brazing sheet technology. In addition, process development is being undertaken in support of traditional markets, such as beverage containers.

MAJOR OPPORTUNITIES IN PROCESS METALLURGY

As has been pointed out previously, metallurgical facilities are built in large capacities, and relatively infrequently. Consequently, opportunities to exploit radical new process technologies occur quite rarely. This situation is particularly relevant in the present decade where overcapacity and weak market conditions make investment in capital-intensive facilities unattractive.

In the present situation, which is likely to prevail for the next decade or so, the most attractive and important technical developments are those which can improve the competitiveness of existing facilities, or those which can be retrofitted in existing operations and produce an adequate return on investment.

The major developments which are urgently needed in nickel and copper smelting and refining are commercializable technologies to improve sulphur dioxide containment. The cheapest and most practicable of these would be the development of a continuous converting process which can be retrofitted to existing batch processing vessels. A more comprehensive solution would be the development of truly continuous smelting processes which can be retrofitted into existing operations. The Noranda reactor producing blister copper is one example of this type of development. Hydrometallurgical solutions are also desirable, but appear to be further away from commercialization.

Treatment and recovery of minor elements is also a problem of general concern providing significant development opportunities. Minor element impurities are causing significant copper quality problems for at least one Canadian producer. Even more important, perhaps, recovery of additional minor elements presently lost in the tailings could increase revenues significantly; these include selenium, gallium, chromium, columbium, and other rare earths.

The other area of significant potential, applicable to all metals in the medium term, is the application of new peripheral technologies to upgrade existing facilities. Opportunities identified in this area include:

- new and improved instrumentation and the application of true process control systems, which will require some improvement in the fundamental understanding or processes.
- development of automated operating systems in hazardous and hostile working environments.
- further development of automated materials handling systems, particularly for casting, anode handling, and cathode stripping and handling.
- development of continuous casting systems producing high quality products and which can be retrofitted in existing facilities.

One of the more promising areas for facility upgrading and possible expansion is zinc smelting and refining. Several promising technologies are under development in Canada at the present time, but all appear to have significant technical risk associated with them which could be reduced by increased further development and possibly demonstration of the technology.

In the longer run, hydrometallurgical technologies appear to be developing as the next major technical breakthrough, with possible application to almost every metal. Canada should be among the leaders in researching and developing this key technology.

Chapter 10. OPPORTUNITIES IN PHYSICAL METALLURGY[1]

INTRODUCTION

A small but increasing amount of the mineral industry's research and development activity is being directed towards new materials and new products, as metal producers seek new markets and defend existing markets. One thrust of this effort is the development of improved product performance characteristics which can increase demand or at least reduce the threat of substitution. The development of thin-walled zinc die casting is an example of this type of response to the plastics challenge in automotive markets.

A second major thrust is the development of new metal products for new and existing applications. These can be existing alloys in new forms, such as the development of nickel crowns for plating; new alloys, such as the new family of lightweight aluminum-zinc alloys; or new products, such as aluminum car bodies.

A third major direction being followed by some metals producers is the development of new high value-added products from byproducts. For example, Alcan and Cominco are both actively pursuing electronics applications for high-purity byproducts such as gallium and germanium. A fourth response undertaken by a small number of companies is diversification into the industries that manufacture competing materials. Noranda diversified into fibre optics and plastics, which were starting to threaten its copper markets, and Alcan and Noranda have both initiated ceramics research and development programs.

These new product initiatives are being managed in a variety of ways. Most of the larger integrated metals companies have product research programs as part of their overall technical programs, although these are typically small, relative to process research and development. Some firms such as Cominco have established product research centres for this purpose. A few, such as Alcan and Noranda, are starting entirely new businesses, small in proportion to the overall corporation, but in some cases growing rapidly.

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1. Useful sources for this chapter included: Science, vol. 191, no. 4228, February 1976, (special issue on materials); F. Gonzalez-Vigil, "New technologies, industrial restructuring and changing patterns of metal consumption", Raw Materials Report, vol. 3, no. 3, 1985, pp. 11-31; and Aviation Week, 21 October 1985, pp. 88-122, and Scientific American, October 1986.

An increasing amount of product research and development is being carried out cooperatively, sometimes on an industry-wide basis. The International Lead-Zinc Research Organization has had a significant program of product research, particularly in zinc, for some time. The Gold Institute, while not performing technical development directly, has commissioned studies of new applications for the metal. The Nickel Development Institute was founded in 1984, and is supported by 14 nickel producers representing 60 percent of world production.

In his study of Canadian multinationals, Rugman notes that Canada's resource-based multinationals face a serious threat from substitute products and that they have focused on the development of good international distribution networks to bolster their marketing strengths.[2] For example, in 1983 Alcan was active in 28 foreign countries, Noranda in 17, Inco in 14, and Cominco in 12. He also notes that reliance on one major product line has in many cases proven to be a disadvantage, and that many of these multinationals are now engaged in product diversification strategies.

In this chapter we will review some of the major opportunities for product innovation in each of the major base metals. In addition, a brief review will be made of opportunities for the creation of revenues from by-products that have not previously been commercially recovered, as well as opportunities in adjacent technologies, such as ceramics.

COPPER

Primary copper demand has been declining in recent years due to the maturing of a number of its traditional markets in developed nations, and substitution in other markets. Substitution has been most noticeable in electrical applications, where copper has been replaced by aluminum in power transmission and increasingly by fibre optics in communications. In addition, aluminum is rapidly threatening copper's traditional heat exchanger market, especially in transportation applications where weight reduction is important.

The copper industry has been slow to respond to these emerging threats. Unlike zinc, there has been no effective industry product research and development organization. Individual firms have been unwilling to invest in new product technologies when no significant potential

2. Alan M. Rugman and John McIlveen, "The Strategic Management of Canada's Multinationals: Who Needs High Tech?", Business Quarterly, Fall 1984.

for maker advantage is apparent. Very little product research and development is currently being undertaken by Canadian producers in copper. According to one industry executive: "The Chileans would benefit most from any work undertaken by us".

The major product development in recent years has been the growing demand for high-grade copper (for which there is no price premium) by customers requiring a greater degree of purity. A number of Canadian producers are finding it difficult to meet these new product specifications.

At the present time, Canadian producers are concerned about using copper's inherent advantages of heat and electrical conductivity to defend existing markets. Thin-walled lightweight components such as radiators are being investigated to stem the encroachment of aluminium in automotive markets. New copper-nickel and copper-phosphorous alloys need to be developed for machinery applications, such as ship-building. These developments might defend traditional markets, although at significantly reduced tonnages.

Expanded uses of copper in traditional markets are also possible through the development of lower-cost processes. One example of this type of development has occurred in Germany where a process has been developed to seam copper sheets mechanically in roofing applications, greatly reducing labour costs and expanding the market. Other opportunities of this type could be developed with appropriate market and product development efforts.

Completely new and significantly large markets for copper are possible, but are considered to be remote possibilities at present, since most demand for this metal is derived from other final products. Research and development in this area is considered to entail high technical and market risk.

NICKEL

This metal is used primarily in alloying applications, primarily in stainless steel and electroplating. Nickel's unique qualities of corrosion resistance and hardness make it hard to replace in traditional applications. Demand suffers, however, when stainless steel output or automotive production falls. In recent years, the major problem facing the metal has been oversupply in the face of a stagnant market.

While some product research is carried out by nickel producers, the major development effort is carried out by manufacturers of stainless steel, particularly the Japanese. In recent years stainless steel has been

meeting increased competition from synthetic materials, such as high performance alloys. Stainless steel producers have initiated a substantial effort to develop new products and markets. Stainless steel producers are also exploring a variety of new markets for existing alloys in areas such as plant construction, and electronics.

Sherritt-Gordon, Falconbridge and Inco maintain some product development activities. In past years, considerable effort was put into creating new product forms which are more efficient in plating and alloying applications. Unfortunately, little or no work is being done on new metal alloys at present in the Canadian mineral industry.

Future efforts should focus on the development of new families of alloys with high value-added applications, which only a few producers, mainly Canadian and French, can supply. These include nickel aluminides with application in gas turbines and reciprocating engines, especially in weight-sensitive uses. New stainless steel alloys are being developed by Japanese stainless steel producers for a wide variety of applications. Zinc-nickel alloys are being proposed for plating applications requiring corrosion resistance and good appearance. Copper-nickel alloys are being proposed for a variety of marine uses.

ZINC

A substantial amount of product research on zinc has been carried out in recent years both by individual companies and by the International Lead-Zinc Research Organization on behalf of the industry. Canadian producers, notably Noranda and Cominco, are among the companies carrying out product research.

A major development thrust in the industry has been inspired by efforts to repel the invasion of its traditional castings markets by plastics, especially for automotive applications. The development of thin-walled zinc diecastings was one of the major results of this effort, and has proven to be very successful. Further incremental development of this technology is thought to be necessary.

Another major research and development initiative takes advantage of zinc's corrosion resistance properties. The development of widespread markets for zinc galvanizing, especially in transportation applications, is being pursued. New technologies are being developed to produce surface finishes comparable to other metals. Zinc's use as a plating material is being expanded, for example in zinc-iron and zinc-nickel plating.

New zinc alloys are also likely to expand the metal's use. Zinc-aluminum alloys are being developed which will have attractive casting

properties and permit its use in a variety of new situations including, for example, bearings. Other properties of zinc that are being exploited include its superplastic characteristics which offer advantages in forming extruded zinc parts.

Zinc producers are also carrying out development activities intended to improve battery designs and increasing manufacturing productivity, in an effort to expand this market for the metal. High value-added applications for zinc are also emerging in the electronics industry. These include batteries, ferrites, and spring alloys. Similar uses in other industries are likely to be developed in the future.

ALUMINUM

Like many other metals, aluminum is suffering from over-supply, stagnant markets, and the impact of substitution. The significant threat to existing aluminum markets from substitution is not widely appreciated, but, in the long run, is probably as equally severe as that facing copper. Several of Alcan's major packaging markets, such as beverage cans and foil containers, are being threatened by plastic substitutions. In addition, increased recycling of aluminium is likely to affect the demand for the primary form.

The aluminium industry has traditionally been more product oriented than other metals, but recently the emphasis on product and market development has been significantly increased. In Canada, Alcan is devoting a significant part of its research and development activity to product work.

Market and product development is focusing on taking advantage of aluminum's light weight, good conductivity and energy storage capabilities. In addition, new alloys are contemplated which will improve its strength characteristics. The major markets targeted for development by the industry include transportation and energy conversion.

In transportation, new applications are being sought for aluminum in automobiles where new alloys and products can be developed for heat exchangers, car frames and body panels. Aluminum-based battery technologies have also been proposed for powering electric vehicles. Railway and subway cars can be constructed from aluminum using new fabrication techniques. New lithium-aluminum alloys are being developed for aircraft applications by a number of producers.

Researchers are also looking to use aluminum's quality as a store of energy in conversion applications. A variety of aluminum air battery configurations have been proposed using different electrolytes, and re-

search programs have been established by the major producers to develop and evaluate alternative approaches. Aluminum applications for solar energy production are also being investigated, as are its uses in ocean thermal energy conversion.

Other new high value-added applications for relatively small tonnages of aluminum, sometimes of extremely high purity, are also being proposed and developed. These include markets in the electronics industry, for super-fine wire, for example, and in nickel-aluminum alloys for turbine components.

A variety of product development initiatives have been proposed and are under way in the industry to defend traditional markets, such as packaging, electrical and construction applications. New forms of packaging are being developed, along with new alloys which offer better strength/weight characteristics. New high strength alloys for construction purposes are also likely to be developed.

LEAD

New applications for lead are not emerging to offset the decline in demand in its traditional markets, particularly battery manufacture. Since lead is often a byproduct of zinc production, lead production levels are not being reduced and prices are extremely weak, making product development work even less attractive. Some work is under way in Canada to support the battery market, but the effort is small.

EMERGING USES FOR BYPRODUCTS AND PRECIOUS METALS

The emerging high-technology industries such as electronics, aerospace, advanced ceramics and composite materials are creating demands for byproducts and rare earths not previously recovered by the mineral industry in Canada. A wide range of these elements is now required in high purity forms. Consequently, small tonnage but high value-added markets are emerging. To meet these demands a variety of new technologies will be required to extract and refine these materials economically. A selected list of some of these elements, (all of which can be produced in Canada) and their uses in electronics are shown in table 42, now somewhat outdated.

Among these elements being recovered are gallium, yttrium, indium, germanium, and selenium. Gallium is being recovered by Alcan from its processes at Arvida, and by Cominco at Trail. Cominco is also recover-

Table 42

SOME METALS WITH ELECTRONICS USES, AND POSSIBLE SUBSTITUTES

Mineral	Uses in electronics	Materials substitutes
Yttrium	Color television phosphors	Other rare earth phosphors
	Magnetic materials	Some other rare earths
Indium	Semiconductors	Tin, lead, bismuth, cadmium
	Solders	
Gallium	Semiconductors, particularly light-emitting diodes	No equivalents
Beryllium	Electrical connector alloys	Phosphor bronze
	Springs	Phosphor bronze, spinodal copper alloys
Germanium	Semiconductors	Silicon
	Optical glass	Boron
Tantalum	Solid electrolytic capacitors	Aluminum, niobium
	Thin film circuitry	Hafnium
Copper	Signal transmission lines	Aluminum, glass optical waveguides
	Electrical conductors	Aluminum
Platinum group	Contact materials	Silver, gold, and their alloys
	Thin film conductors	Aluminum, tungsten
Cobalt	Magnetic alloys	Nickel, iron
	Ferrites	
Gold	Platings, contacts	Various, but inferior
	Thin film conductors	Tantalum, aluminum
Silver	Contact alloys	Copper, aluminum
	Conductors	
	Conductive paste	
Tin	Solders	Lead (partial)
	Copper alloys	Aluminum bronzes, stainless steel
	Superconductors	Other A-15 compounds
Aluminium	Conductors	
	Insulating ceramics	Various
Nickel	Magnetic alloys	Cobalt, iron
	Spring alloys	Various
	Ferrites	

Table 42 (continued)

SOME METALS WITH ELECTRONICS USES, AND POSSIBLE SUBSTITUTES

Mineral	Uses in electronics	Materials substitutes
Tungsten	Light filaments	
	Evaporator filaments	
	Metallizations	Aluminum
Antimony	Semiconductors	
	Fire retardants	Halogenated aromatics
	Solders	Tin, lead, bismuth, cadmium
	Cable sheathing	Calcium
	Batteries	Calcium
Lead	Batteries	Nickel-cadmium, and others
	Cable sheathing	Polyolefins
	Solders	
Rare earths	Magnetic crystals	Various rare earths
	Optical crystals	
	Phosphors	
Niobium	Magnetic alloys	Iron, nickel, cobalt
	Superconductors	Other A-15 compounds
Manganese	Ferrites	
	Superconductors	
Zinc	Ferrites	
	Spring alloys	Various
	Batteries	Various

Source: A.G. Chynoweth, "Electronic Materials: Functional Substitution", Science, 20 February 1976.

ing indium and germanium at Trail. Yttrium is being produced by Denison Mines at Elliot Lake. Selenium is recovered by Noranda Inc. at its CCR refinery. Lithium and tantalum are available at Tantalum Mining Corporation's mothballed Bernic Lake deposit. New uses for these and other elements are possible, but there is little work under way in Canada at the present time.

Precious metals are also being used increasingly in high technology applications, in addition to electronics, and development work is needed to expand such high value-added applications. Gold's heat-reflection properties can be developed for a variety of aerospace and construction applications. Gold and platinum metals can be used as catalysts in fuel cells as well as protective coatings. Silver can be used in oxygen feed pumps, and is increasingly replacing gold in many electronics applications.

PRODUCT OPPORTUNITIES IN ADJACENT TECHNOLOGIES

The new technologies and industries listed above which provide new high value-added markets for Canadian mineral products also present attractive growth opportunities for Canadian mineral firms. Through a variety of internal business development activities, joint ventures, and acquisitions, Canada's integrated mineral producers are taking positions in some of these industries, which not only provide significant growth opportunities in themselves, but also provide windows into these rapidly changing technologies through which new opportunities can be identified.

Several mineral companies are either exploring or actively pursuing opportunities in advanced ceramic materials. These include Alcan and Noranda, which have natural interests in this industry through their alumina businesses. Special aluminas are a key raw material in this industry. Applications for these materials include electronics, automotive engines, cutting tools, and industrial machinery. Japan is the technological and commercial leader in this industry, which it is estimated, could have shipments of $30 billion within 25 years.

Composite materials are another area of opportunity for Canadian mineral producers. Metal composites appear to offer important market opportunities in the future; both Alcan and Noranda have small programs in this area, and Inco already produces and sells metal-oxide composites (mechanically-alloyed products) at prices as high as $40/lb. Rapid solidification technologies hold the promise of new material properties leading to innovative applications. Alcan is already active in this field, and both CANMET and Noranda Inc. are examining possible research programs.

Canadian mineral companies are also actively pursuing diversification into electronics, especially semiconductor materials. Alcan has a subsidiary in the gallium arsenide wafer business and Cominco has a small division looking at this technology along with several other related opportunities.

INNOVATION OPPORTUNITIES IN PRODUCT DEVELOPMENT

The value of product innovation continues to be generally underestimated by senior executives in the mineral industry. Failure to develop new products will leave Canada in the position of being a residual low value-added supplier, as it is becoming increasingly apparent is the case in forest products. In this eventuality, Canadian suppliers will be price takers, and have little capability to offset the industry's cyclical down-turns.

A problem with identifying major opportunities in new product development is the pitifully small level of activity and resources allocated to this area by Canadian mineral firms. The significant exception to this case is Alcan, which spent over $40 million in 1985 on product research and development alone. David Culver, Alcan's president and chief executive officer, publicly stresses his company's commitment both to technology as a cornerstone of corporate strategy and to product innovation as a key component of the corporation's future success.

Even Alcan's level of spending is low in comparison to that of U.S. and Japanese firms in comparably mature industries, which may spend up to 2 percent of corporate revenues on product innovation alone. In Canada, there appears to be an industry belief that spending on product research and development is not of value unless the corporation is a dominant player, such as Inco in nickel or Alcan in aluminum.

In general, Canadian mineral product development activities are small, fragmented and unlikely to bring about any major technological breakthroughs. For example, Noranda's research centre has a total budget of approximately $1 million annually for product research and development in zinc, copper, aluminum, lead, selenium and other metals. Cominco's product research centre has an operating budget slightly in excess of $2 million annually. These levels of spending cannot accomplish much besides customer support and incremental developments.

Yet major new product opportunities do appear to exist which the mineral companies could pursue. At the very least, there appears to be a growing need for expanded defensive product and market development programs, to prevent or delay the entry of plastics and new materials into traditional metal markets. Alcan is making a major effort in aluminum, and cooperative efforts are developing in zinc and nickel, although such ventures have not historically enjoyed high rates of commercial success.

There also appear to be significant opportunities in almost all metals to develop and commercialize new alloys with improved performance characteristics. Some work has been done in this area, but virtually none is being done by industry at the present time. There is an urgent need for R&D in alloys, especially in cooperative programs with potential users and customers. For example, the development of joint development programs with transportation firms could lead to significant new products for these markets, as has been the case in the past with aluminum.

High value-added products in emerging industries also offer significant opportunities to develop new markets which may be small in tonnage but extremely profitable. These exist particularly in electronics, advanced materials, and aerospace. Canadian mineral firms need to develop

more "windows" on the development of technologies in these industries, and on the resulting new product opportunities. The chance to enter these industries directly, through diversification, may subsequently follow these initiatives.

At a Virginia workshop on new materials sponsored by the Federation of Materials Societies, participants identified a number of lessons arising from the transfer of leadership from the USA to Japan in silicon production technology.[3] For successful manufacture of advanced materials, they recommended:

- first and foremost, collaboration between user and supplier;
- financial commitment and significant capital investment, since production facilities will probably need retooling every 10-12 years;
- quality as the single most important goal, a goal requiring close attention to techniques of quality control;
- intra-industry cooperation for technology transfer;
- changed perceptions of trade restraint;
- greater flexibility in manufacturing;
- seeking new markets and new products, rather than simply expanded markets for traditional products.

The tangible value of possessing products which others cannot offer is evidenced by the fortunes of Inco and Falconbridge in the nickel business. Their high quality nickel plating and cobalt products, which few other producers can offer, allow them to dominate market segments in which they can command significant premiums over LME and melting grade prices. This advantage contributes significantly to their profitability, especially in depressed periods. The challenge facing the Canadian mineral industry is to develop a stream of such products, which will allow them stay on the cutting edge of technology and to dominate the premium market segments for the metals they produce.

3. Cited in Strategic Materials Management, Washington, D.C., vol. 6, no. 16, 15 August 1986.

Chapter 11. CONCLUDING OBSERVATIONS

INTRODUCTION

If studies could solve the problems of the Canadian mineral industry in particular or of technological innovation in general, they might long since have been resolved. Royal commissions, special reports, and in-house and commissioned studies have for decades been investigating Canada's economic policies, industrial strategies, science policy, technology, trade policies, the mining industry, skilled manpower, etc. and have presented policy makers with a veritable avalanche of recommendations, very few of which have been acted upon over the years.

Canada is not short of constructive suggestions for creating a climate for technological innovation in the mineral industry. Nor is there any shortage of examples of successfully innovative climates, for example in other countries such as Finland and Sweden in mining, and Japan in high technology. Our shortcomings appear to lie in three major areas:

- the decision-making process which determines the level and allocation of funding for R&D and new technology, and the effectiveness with which these funds are spent;
- the focus of present R&D efforts, which are not always directed at the major areas of need and opportunity;
- attitudes toward innovation, as reflected both in the level of R&D expenditures and in the rate at which innovations are taken up.

The decision-making process, both within industry and in government, sets up barriers or constraints to effective funding and administration of R&D and innovation. However, given attitudes and political will that are supportive of technological innovation, immediate improvements can be made in the structures and processes that allocate the R&D funding, carry out R&D, and exploit the resulting innovations. This study, therefore, concludes by discussing constraints within the present decision-making and implementation systems and, in the recommendations, suggests steps that might be taken to overcome them.

Focus of effort is a crucial ingredient when the opportunities are many but the resources are limited. At present, there is no overall focus on the part of industry or government on key areas of concentration for R&D and technology, although positive moves in this direction have recently been initiated. This study has identified a broad spectrum of areas of opportunity in all phases of mineral industry activities. The

concluding observations include suggested criteria for rational selection among the many opportunities for innovation and some of the major areas for concentration.

Changes in attitudes generally occur as the result of external pressures, such as the economic hardships that have "wonderfully focused the attention" within industry and triggered increased efforts at innovation in the last few years. Governments, although somewhat insulated from these economic pressures, have also begun to respond to them. This study, although it can provide information, comparisons, and advice, cannot of itself affect the attitudes of industry management or the political will of the public or of the public servants. In dealing with questions of attitude therefore, the study concentrates on identifying rather than resolving attitudes that constitute constraints to innovation. The recommendations suggest mechanisms to improve communication.

Perhaps the strongest incentive for improved attitudes toward innovation would be a demonstration of the results of increased effectiveness of R&D and technology efforts, in the form of improved profitability that can be directly attributed to innovation. Studies have in fact shown that the financial returns from research and development can be significantly higher than those from investments in physical capital.[1] Such findings provide powerful ammunition in arguing for additional R&D investment.

The Canadian mineral industry cannot remain vigorous in the long term without these additional investments. Investments in research and development and technology will be crucial to the quality and vitality of survival. Without them, Canada will be relegated to the position of a high-cost residual supplier of commodities; through new technology, the industry can maintain a preeminent position in the world industry. Investments in new technology must be viewed, not as a luxury, but as essential to the future health of the industry.

LEVEL OF FUNDING

It is clear from chapters 4 to 10 that the opportunities for technological innovation far outdistance the resources available to realize them, at present levels of funding. The overall level of spending on new technology by the mineral industry and by governments in Canada is inade-

1. See, for example, Ministry of State for Science and Technology, "Summary of Productivity Analysis in the Mining Sector", mimeo, August 1986. The net rate of return for R&D was estimated at 31 percent, while the comparable rate of return for capital was found to be 21 percent.

quate. Less than 1 percent of total industry revenues are allocated to R&D, and total technology-related expenditures probably amount to no more than 1.5 percent of revenue. This commitment is below that of leading competitor nations, and is insufficient to maintain Canada as a first-rank mineral producer in the long run.

The overall level of research and development funding may seem at first glance to be the fundamental problem of innovation in the industry. However, all the other problems discussed below affect the ultimate effectiveness of this technical effort. We believe that eliminating some of these problems will increase the efficiency of the present level of funding, which may have the additional benefit of improving cash flows as well as attitudes towards technological innovation in the industry.

FOCUS OF ACTIVITIES

Present Focus

The problem of low R&D funding appears more acute when we consider the present focus of R&D and technology spending, and compare it to the business focus of the industry. The technical development efforts by the major integrated producers (the only companies that have reported significant R&D programs) are directed predominantly towards the last stage of mineral production, extractive metallurgy. This has been largely responsible for Canada's strong competitive position in smelting and refining. At the same time, however, the mining and exploration stages have been relatively neglected in terms of R&D, a neglect that makes little economic sense.

Exploration and mining companies constitute over 90 percent of the total establishments in the industry. Exploration is the most risky and perhaps the least understood aspect of the business, and the future of the business hangs on the ability to locate new high-quality mineral deposits. Yet junior and producing mining companies have virtually no R&D programs in exploration techniques and equipment (although the GSC, some universities, and a few equipment companies have made significant efforts).

Metal mining in particular has been the underpinning of the industry's strength, and the mining stage has the highest mineral losses and inefficiences of any of the production stages. It is both labour and capital intensive, heavily dependent on technology, and the source of over 50 percent of metal production costs. Furthermore, the ability to mine and treat ore that is presently marginal or uneconomic would extend

the life of many mines in Canada, effectively creating new resources. Nevertheless, it is in mining that Canadian R&D effort lags most. There is great dependency on foreign equipment suppliers. European mines have often led Canadian operations in the adoption of both new methods and new equipment. Relatively little money is allocated toward mining R&D and technology in Canada: perhaps 10 percent of all technical development expenditures by mineral companies are in this area. Inco, the only mineral producer with R&D expenditures exceeding 1 percent of sales, is an exception in the area, with a major commitment to mining R&D that is already yielding significant productivity gains in its underground mining operations.

It is also in the mining stage that management conservatism and risk-avoidance are most prevalent. This may be one of the reasons why change has been slow in the past, and why relatively little spending has been undertaken in support of mining R&D. Yet there appear to be major opportunities to improve mining technology radically, in both existing and new mines. The challenge facing the industry is not just innovation, but, much more importantly, in ensuring that existing and new techniques are widely adopted and implemented.

Therefore, while we do not believe that the level of R&D and technology effort in metallurgy is excessive or even adequate to exploit the potential opportunities, we do feel that the present focus of R&D funding fails to take advantage of the areas of greatest need and opportunity, which seem to lie in mining and exploration.

Criteria for Future Focus

It was noted in chapter 1 that technology can be classified as central to the basic operations of mineral production, or core technology; or, it can be peripheral. Innovations in core technology generally arise from within the industry itself, either in Canada or elsewhere. Peripheral technologies, which include the emerging fields such as robotics, information sciences, and biotechnology, are generally advanced outside of the mineral industry; the resulting innovations can then be adapted and transferred to mineral-related activites.

A distinction has been drawn between major breakthroughs and incremental innovations. The vast majority of innovations in the sector are of the incremental nature, in both core and peripheral technologies. These sorts of advances can produce cost reductions in the order of, say, 1 to 20 percent within their area of applications, and cumulatively have succeeded in keeping the industry viable. They are, however, con-

stantly being eroded by increasing costs that are beyond the control of industry, particularly a range of government mandated or administered costs for services such as energy, transportation infrastructure, municipal services, and workers' compensation. Furthermore, competitors may lead, or follow closely, in such incremental innovations and thus encroach upon any resulting comparative advantage.

Major breakthroughs, although infrequent, and often associated with high risk, can contribute larger competitive advantages. They can arise in several ways. One is from basic or applied research and development in adjacent and other fields; for example in physics for advances in geophysics and new materials, in chemistry and biotechnology for some of the advances in hydrometallurgy, and in civil engineering and construction for large-scale excavating equipment. Another source is the combination of previously unrelated technologies into an integrated new approach: for example, microcomputers and rock mechanics, for micro-seismic applications.

The criteria for selecting a future technology focus should be selected with a view to achieving efficient allocation of scarce resources as well as effective technological innovation; in other words, not simply "a bang for the buck", but the biggest bang. We believe that the study indicates that the greatest value in future technological innovations will arise from advances that lead to one of the following:

- a major technological breakthrough in one of the mineral industry core technologies - for example, a major breakthrough in geophysics which would enhance exploration efficiencies by an order of magnitude; or

- a new total system technology which, while not necessarily embodying breakthrough innovations, combines core and peripheral technologies in new ways - for example the introduction of a continuous mining system that could be easily adopted by existing mines without major capital expenditure; or

- a defensible product or market innovation that expands the demand for the output of existing Canadian production facilities - for example, a major breakthrough in materials science which would permit metals to recapture a significant share of the markets being lost to plastics.

The innovation should be in an activity that offers significant scope for improvement and can be exploited reasonably quickly. It should also help

companies to meet regulatory requirements with respect to health, safety and/or environmental protection.

Over the long term, all three types of innovation will be required to meet the competitive challenges facing the mineral industries. In the short term, however, the most feasible type to stimulate is that based on the adoption of advanced technologies in adjacent fields by mineral industry companies. Most of these technologies already exist, and the lead times to adapt them for application in mining will be much shorter than those required for the commercialization of breakthrough technologies derived from basic or applied research.

SPECIAL MANAGEMENT CONSIDERATIONS

Risk Factors

The Canadian mineral industry has distinctive managerial traits which are at the same time both an asset and a liability. These arise largely from the nature of risk in the industry and its unique position in Canadian industrial history. Industry executives perceive themselves to be risk-oriented in new business decisions, but they tend to be conservative, traditional, and risk-averse when operating.

The general perception in the industry is that there are extremely large elements of business and financial risk in bringing new mines into production. Initially, there is considerable risk in exploration: i.e. in finding a new orebody that will be economic when brought into production. Statistics suggest that, on the average, about $35 million is spent on exploration to discover an average Canadian nonferrous metal mine. Delineation of the orebody may be expensive, if, as is often the case, a shaft has to be sunk before the full extent of mineralization can be determined. Up to $50 million may be spent before a mining company is sure that an economically viable operation exists.

Once the decision to put a property into production is taken, construction is expensive and time-consuming. Typical construction lead times for new mines in Canada are between 3 and 5 years, and the costs of a new mine-mill complex, depending on size, may vary from $25 million to $500 million. A new integrated mine-mill-smelter-refinery complex on the scale of the Kidd Creek operations would today cost in excess of $1 billion.

Even when these risks have been dealt with, there is no assurance that a new mine will be profitable, because of the cyclical nature of metal markets. A new operation entering production at the peak of a price

cycle may pay off its capital costs in five years. One that enters production near the bottom of the cycle may never return its investment.

Given the inherent uncertainty in exploration and mine development, it is understandable that mining executives wish to minimize the technological risk in new operations. This attitude means that untried technologies will not be incorporated in new mines unless absolutely necessary. More typically, it has meant that new mines are often developed with mature technologies that the managers of the operation are extremely comfortable with. While this strategy does minimize technological risk, it may mean that operations have higher costs than desirable.

Once a mine is in operation, major technological change is difficult due to the relative inflexibility of mine designs. Changing from one mining method to another, for example, while not impossible, is perceived to be risky. Only recently, when many firms were faced with a choice of innovating or dying, have these attitudes moderated somewhat, with the result that a considerable number of new technologies which have been "on the shelf" for some time have been put into use and commercialized.

Organizational Factors

Within mineral industry operations, there are many barriers to successful innovation arising from organizational and operational factors. As shown in this study, there is no shortage of ideas for technological change in the industry. These exist throughout mining companies, as well as in related institutions such as consulting firms and universities. The main problem facing the industry lies in implementing these potential innovations and ensuring that they are rapidly diffused throughout the sector.

Organizational factors that inhibit innovation include reward systems, resource allocation processes and company structures. The traditional mining bonus, for example, is structured in a way that encourages operators to resist changes which may reduce their income, even if only temporarily. At more senior levels, continuity of operations and meeting short-term production goals are valued more highly than innovation, which may disrupt routine. "Don't rock the boat" and "if it ain't broke, don't fix it" are common operating maxims in the industry.

With the possible exception of exploration, corporate resource allocation has traditionally been slanted towards fast-return capital-intensive projects, rather than technological improvements which may have a longer payback and fewer tangible benefits. When major funds are required for commercializing a new technology, engineers interviewed in the course of this study reported that executives have traditionally shied away from a

meaningful commitment. They described, for example, new hoisting, materials handling, and equipment technologies that have been under development for up to twenty years, but which have never received adequate funding to permit commercialization.

Company structures inhibit innovation by establishing organizational and geographic barriers between the groups that must work together to introduce successful innovations. Research and development, engineering, and operating groups are often remote from each other, and report to separate executives. Within these areas, organization tends to be by discipline, which does not facilitate the integration of efforts required to bring about success.

Among the operational barriers impeding change, the lack of sound methodologies for technical project selection, implementation and control appears to be particularly important. In the absence of these mechanisms, innovations are frequently implemented poorly, late and over budget. Poor performance then contributes to the relatively poor perception of this activity by senior executives. Another problem is the failure to establish multi-disciplinary teams to implement systems innovations, due to organization barriers. Operationally, these are all reinforced by the loss of continuity in technical development and implementation which arise from the cyclical nature of the business, and the stop-go syndrome which results from consequent short-term cost reductions and operating cutbacks.

Complementing these conservative influences in operations is the industry's traditional approach to labour relations. Most mineral industry operations are unionized, and management-labour relations have traditionally been adversarial. This might be of little account in other capital-intensive industries, such as oil, where labour is only a small proportion of operating costs. However, in Canadian mineral operations, labour may account for between 30 percent (in refineries and open-pit mines) and 60 percent (in some underground mines and older smelters) of total operating costs. Under these conditions, Canadian mining firms have benefited relatively little from technological and methods improvements which their skilled work forces might have generated in more cooperative work environments. Moreover, the labour force has been characterized by a relatively high degree of resistance to new technology, and sabotage in underground mines is not uncommon. For many years, Texasgulf Inc., the initial owner and operator of the Kidd Creek mine, provided a model of management-labour relations (and safety practices) for the industry. More recently other firms have tried, with varying degrees of success, to implement employee involvement activities aimed at improving working relationships and productivity.

A New Direction

There can be little doubt that the Canadian mining industry, sheltered by a strong demand for its products, in many instances became complacent, top-heavy, and ineffectual in its management of costs during the 1960s and 1970s. Organizational and technological innovation lagged, and the industry failed to keep up with emerging managerial practices. During this period, the declining gold mining industry served as a model of what can happen to other metal producers during an extended period of depressed demand and prices. Even a ten-fold price increase for this commodity was not enough to significantly alter production patterns in Canada, as costs rose in step with prices for most producers. However, the recent recession has moved executives in all firms to take action on costs, innovation, and productivity. Costs have been dramatically reduced in many firms, and labour productivity gains of up to 100 percent during the last four years have been recorded.

Whether these changes will be maintained has yet to be determined. Some cost reductions have been made at the expense of supervision and labour; this may harden their attitudes still further towards management. Expenditures on research and development remain at less than one percent of revenues, extremely low for a technology-intensive industry of this type. Management in the industry is alert to its problems, but must maintain the industry's momentum in the direction of cost-cutting and productivity improvements through innovation.

Lack of An Indigenous Equipment Industry

Many process and production innovations in the mineral industry are embodied in equipment of one type or another. Especially at the later stages of design and demonstration, mining and processing companies need to work closely with domestic equipment supply companies with a core of innovative capabilities. In Canada, this capability is lacking, as the equipment industry is dominated by the subsidiaries of foreign equipment manufacturers which usually possess no technical development resources in Canada. Canadian mineral firms have not diversified into a Canadian equipment manufacturing capability. Where Canadian companies have established technical linkages with foreign firms to develop new equipment, potential benefits from the future sale of this technology have been usually lost to Canada.

Canadian-owned equipment suppliers tend to be small, poorly funded and possess only limited innovation capabilities. The recent capital

spending cutbacks by the mining industry has been particularly detrimental to these firms. Even Jarvis-Clarke, formerly the largest Canadian-owned firm but recently purchased (and resold) by CIL-ICI, has been forced to reduce its engineering and design staff. The Canadian mining industry has generally been unwilling to provide up-front funds for equipment upgrading by Canadian manufacturers. This has severely limited their ability to compete with offshore suppliers. Mining companies do offer "guaranteed sales" to offshore supplies for equipment modification, but such guarantees are generally insufficient to enable Canadian manufacturers to secure the necessary financing.

Inco's establishment of Continuous Mining Systems and Spar Aerospace's growing ties with the mineral industry are examples of important industry initiatives towards direct links between mining and equipment manufacturing in Canada.

SPECIAL GOVERNMENT CONSIDERATIONS

The Government Policy Process

Governments are presently handicapped in establishing research and development policies for the mineral sector by a number of factors, some of which are unavoidable and some of which can be remedied. Among the unavoidable factors are such political necessities as:

- the need to treat various economic sectors in an equitable manner;
- the need to encourage economic activity and employment in depressed regions and communities;
- the need for exports to meet the pressures of the balance of payments accounts, and the associated need to avoid the appearance or practice of subsidizing an export industry;
- concerns for environmental and health and safety issues.

Among the correctable factors that are counterproductive in establishing science and technology priorities are:

- the proliferation of departments involved in this area, and the resulting conflicts, gaps, and overlaps in policies and programs;
- inadequate information in government departments about the industry's current performance in such areas as profits, productivity, and comparative advantage;
- inadequate information on price and market trends and forecasts;

- lack of technology awareness and expertise at the senior levels of policy analysis and decision making;[2]
- insufficient use of rigorous and systematic analyses of the potential economic and social impact of policy changes, such as specific technical breakthroughs that can be anticipated;[3]
- by contrast, a failure to stand back and identify key areas of need and opportunity;
- the short-term orientation of political decisions, in contrast with the long lead-times required to carry innovations through from conception to demonstration and subsequent commercialization;
- reluctance of the government to share the risks of technical innovation (especially demonstration and commercialization) with the private sector, or accept the inevitability of occasional failures.

The mineral industry's principal needs in terms of government support for its process of restructuring are:

- policies that complement industry's attempts to reduce costs and strengthen international competitive position over the long term, rather than policies that bail out losers, for whatever reason, to the detriment of the economically sound firms;
- more effective allocation of government R&D and technology transfer funding and efforts, from basic research through to demonstration and commercialization.

Government R&D and Technology Programs

Barriers to innovation can arise out of the very structures and processes created for allocating funds and for directing and evaluating federally-funded research and development. These structures are essentially all in-house government bodies. Once the overall level and distribution of funding has been established at the Cabinet committee level, these departments and agencies are in control of resource allocation within their area of operation.

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2. See, for example: M.J. Wojciechowski, ed., Mineral Policy Formulation: the Role of Scientific and Technical Knowledge, Centre for Resource Studies, 1982.
3. See, for example: Wassily Leontief, 'The Choice of Technology', Scientific American, vol. 252, no. 6, June 1985, pp. 37-45.

Allocation decisions (except in the case of NSERC) are made and priorities are established by civil servants, who must deal with government regulations and political necessity. They may consult with but are not accountable to university and industry advisors. They are not subject to the same economic pressures or practical demands imposed on industry decision-makers, who must make their decisions in the face of such uncertainties as severe fluctuations in cash flows, discontinuities in the quality and nature of ore resources, changes in demand, and competition from other suppliers.

In-House R&D

For federal in-house R&D, which means essentially CANMET plus some GSC and NRC activities, there is frequently no effective peer review of work in progress, its rate of progress, quality, and relevance; i.e. review of the sort imposed by financial "payback" considerations in industry or by publishing requirements in a university. Increased and more effective technology transfer will require increased consultation and communication, and more shared projects with industry.

Contracts

The government contracting-out system suffers from similar problems, and some additional ones of its own. Priorities and funding allocations are established in-house, as are contracts' criteria and methods of evaluation. The criteria and methods applied by the federal Department of Supply and Services are apparently designed primarily to reduce risk and prevent funding abuses, rather than to encourage creativity and permit the exercise of peer judgment in evaluation of the quality and usefulness of the results. Contracts are widely criticized for their complicated application procedures, excessively rigorous reporting requirements, and lack of feedback or follow-through on conclusion. In general, the supervision and evaluation is felt to be of an administrative rather than a scientific or technical nature, and is often lacking in continuity, as scientific officers move to different responsibilities.

Grants

The principal federal granting body for mineral-related R&D is NSERC. The committee system for NSERC grants for university research is felt to

be satisfactory, in both principle and practice, although a number of reservations were expressed by individuals interviewed in the course of preparing this study, including:

- There is no committee specifically for mining, and over the years there has been a feeling that mining applications were not well received by the various committees that considered them, and received a disproportionately small share of funding.

- Researchers and committee members alike commented on the fact that it is not the committees of experts but rather a rapidly expanding bureaucracy within NSERC that establishes policies and overall funding allocations, and determines the focus for special short-term programs such as strategic grants.

- Researchers feel that the criteria for selection of NSERC committee members should be scientific and academic excellence, not regional or other representational considerations.

- Researchers complain that inadequate provision is made within the granting system for equipment maintenance. This can lead to ineffective use and premature abandonment of very costly capital equipment. It is easier, it seems, to get a grant for new equipment than to find smaller sums to keep existing equipment operating.

- The concept of strategic grants (which envisage that a major technological breakthrough can be achieved with the aid of a large grant, or a collection of focused grants, for 3-year periods) is simply unrealistic. It leads to surges in spending which may be largely wasted if the grants are terminated for reasons related to changing program focus rather than quality or usefulness of the research.

- Interdisciplinary and industry-university proposals to NSERC appear to have a more difficult time in the evaluation procedure, in spite of the fact that most innovative R&D desperately needs an interdisciplinary approach.

NSERC, NRC, and DRIE grants for industrial research and development have been useful sources of funding for some mineral firms. However, one criticism of these programs is that the effort required for application procedures, information, and progress reports is out of proportion to the dollar value of grants, making some companies reluctant to use them. A notable exception is the IRAP grants, which are very simple in concept.

ISOLATION AND THE BLINKER SYNDROME

Isolation of the various enterprises in the public, private and academic "solitudes" in the mineral sector in Canada has contributed to a narrow approach to problem-solving. For industry, this is fostered in part by the geographical isolation of many of the exploration and mining operations, and worsened by a tendency towards secrecy among many establishments. The lack of a central industry agency responsible for focusing innovation is a serious additional handicap. The Canadian Institute of Mining and Metallurgy (CIM) has come closest to this role over the years, at least in the area of communication about innovative efforts. The CIM offers opportunities for presentation of technical papers, many of which deal with innovative solutions to problems of common interest to the industry. However, the papers published in the CIM Bulletin and special publications represent only a small percent of the presentations given each year at the general and section meetings. The remainder are, to all intents and purposes, lost to the industry.

With some commodity-specific exceptions (e.g. coal, asbestos, potash, HDRK, NiDI), there are still few joint ventures between companies, and few with universities. Most research organizations have neither the mandate nor the resources for the long-term effort needed to rework traditional methods, processes, and equipment. Canada has no national organization similar to AMIRA in Australia or the Chamber of Mines in South Africa, which could provide an industry-government focus on technological problems and support critical-mass innovation efforts. AMIRA, for example, gives the Australian mining industry great leverage for its $3 million per year, through the role it plays in allocating the much larger government contribution to its projects. The technology initiative of the Mining Association of Canada in moving toward a national focus for mineral-related R&D, and the chairs in mining that are now being established at several Canadian universities with strong industry and government support, are further evidence of moves in the right direction.

In universities, isolation has been a problem for both basic and applied research in mining. The lack of attention to basic mining R&D is evidenced by the paucity of mining proposals to NSERC and the lack of an NSERC committee for mining. Applied research on the other hand is more active, funded to a large extent by CANMET contracts. Both CANMET and universities suffer from a relative lack of industry involvement in identification of priorities and in joint ventures in the projects themselves.

In metallurgy and geology, basic R&D funding is more readily available. The emphasis in these departments within universities has gen-

erally been in basic R&D, rather than in applied areas of direct economic benefit to the industry such as economic geology, mineral exploration, and extractive metallurgy. It would appear that there are some obstacles to direct links between basic and applied research in these areas, as well, as a result of the "blinker syndrome" discussed below which tends to separate science from technology.

Government programs, including those of EMR, and other support programs that are nonspecific to the mineral industry, have no direct industry participation in the decisions that allocate funds, establish administrative procedures and project criteria, and evaluate project results. This is a necessary requirement of in-house government programs. There is evidence of industry frustration with the ineffectiveness of the existing advisory committee system for improving the focus and effectiveness of R&D and technological innovation programs within government, although recent improvements have been made. Industry, however, has shown little interest in the advisory process until recently; many CEOs were not even aware that their staff were involved in such activities.

The "blinker syndrome", as we have chosen to call it, is a form of isolation that arises from attitudes rather than geographic or organization barriers. It is found between and within all the solitudes of the mineral sector, at all levels. It compounds the effects of isolation in the sector, and resembles the "not-invented-here" syndrome, although its roots are deeper and its effects are wider. Industry is isolated from government, and both are isolated from universities, not just physically, but in attitudes towards the quality and usefulness of work being done outside one's own particular niche. Within all three sectors, inside companies, government organizations, and especially university departments, geologists are split into various groups; exploration geologists rarely work with mining engineers; metallurgists have their own world, also subdivided into specialities. Basic scientists consider their work more "pure" than that of applied scientists; applied scientists feel their work is more in touch with the "real world" and therefore more useful; relatively few researchers make the crucial link between basic and applied. Except within a few major integrated mining firms, mineral economics and marketing are unknown specialties in the industry. Graduates of one university look at their discipline differently from graduates of others. Gold miners from Quebec approach technical problems vastly differently from base metal miners in Ontario.

The blinker syndrome is subtle, subjective, always denied by those worst afflicted, and difficult to overcome. It is very costly to the industry, however, because it interferes with the free flow of ideas, and

with the process of transfering innovations from one place, or one type of mining, to another. Like isolation, it leads to duplication of efforts, to wasted efforts on nonproductive research, and to lack of attention to areas of greatest opportunity. It also interferes with problem-solving, because it discourages multidisciplinary approaches and fresh views of old problems.

Chapter 12. RECOMMENDATIONS

INTRODUCTION

Here we propose strategies for the mineral industry in Canada which have the objective of facilitating technological innovation, as a contribution toward maintaining Canada's position as a profitable and first rank mineral producer beyond the end of the present century. Three distinct aspects are identified, which correspond to short, medium, and long-term time horizons in terms of expected results. All three aspects should be pursued immediately, if not sooner.

For short-term results, the strategies must provide the industry with the best available technology to ensure it remains viable and competitive. These recommendations are aimed essentially at catch-up activities. State-of-the-art technologies, in Canada or abroad, in mining or in other industries, should be acquired through such means as joint ventures, forward integration, purchase, or license, and should be implemented rapidly in areas of greatest need and opportunity. Promising new Canadian-developed technologies which are near to commercialization should receive special attention and funding to ensure rapid implementation.

The medium-term objective is to establish a solid base of technological capability and expertise in the Canadian private sector, still with a focus on technologies with quick returns in areas of greatest opportunity, but with increasing attention paid to developing domestic capability in methods and in equipment manufacturing, rather than relying on technology transfer from abroad.

In the long term, the objective is to establish Canada as a world leader in selected areas of mineral-related research and development, and in innovation in methods and equipment. Properly focused, this would ensure that Canada will remain a low-cost producer, as well as a supplier of new mineral products and materials with high value-added content. It would also have a viable mining equipment industry. Long-term viability in technological innovation must be built upon a foundation of strength in basic R&D.

However, financial and management considerations will limit the industry's ability to provide all the financial resources necessary to realize these objectives. The first and most urgent task is to generate a broad and effective commitment to R&D and innovation at senior levels in the industry. Governments should join industry in the necessary policy formulation and education activities, and offer financial support and encour-

agement for private sector implementation. Government should at the same time continue to give strong financial support to basic R&D activities, and encourage industry to do likewise.

It should be noted that these recommendations were initially prepared in response to a request for information from the Ministry of State for Science and Technology, and therefore may seem to be disproportionately directed to government rather than industry initiatives.

STRATEGIES FOR SHORT-TERM RESULTS

These are for immediate implementation, and aimed at economically sound short-term results in cost cutting and productivity improvement.

1. **Private and public-sector efforts should focus on the acquisition and implementation of existing state-of-the-art technology.**

The quickest and cheapest way to inject cost-effective new technologies into the mineral industry is to acquire them from available state-of-the-art sources wherever possible. Where such technology is not available, domestically or abroad, Canadian technical development should be encouraged in promising new technologies which have the potential for rapid commercialization.

2. **Canadian industrial intelligence networks should be established and funded to ensure that the required information is obtained.**

To implement this catch-up strategy effectively, Canadians have to examine what their colleagues and their competition are doing, and also understand the potential contribution of technical developments in adjacent industries for the mineral industry. In the present climate of economic constraint, many firms have slashed travel budgets and conference attendance. There are also very limited discretionary funds for monitoring developments in other industries. This trend should be reversed, and governments could also contribute to funding programs for these efforts. An on-line subject key-worded international patent information system would be a critical part of this activity.

3. **Industry and government support for demonstration and commercialization of promising Canadian-developed technologies should be increased.**

A major barrier to innovation has been identified as the lack of funds available for the later stages of innovation, which are also the most costly. The mining industry has had very few ties with the equipment manufacturers in the past. EMR and NSERC offer support for the earlier stages of research and development, but the funding of subsequent steps is scanty. DRIE, which has the mandate to support the equipment manufacturing sector, specifically excludes mining per se. In addition, much of the required demonstration and piloting work does not take place inside research and development facilities, but in the workplace instead, and is consequently ineligible for R&D support through tax incentives. Industry and government support of the demonstration and commercialization of technologies identified by industry as having high potential in identified areas of opportunity would almost certainly yield significant value.

4. **An industry-operated extension program should be established to upgrade technologies in smaller mining enterprises that may have limited technical resources.**

As noted in this study, most Canadian mineral enterprises have no research and development capability, and only limited capability to introduce new technologies. Finding ways to facilitate effective technology transfer into these firms would greatly assist their chances for future survival. Using the Farm Extension Programs or the more recent program for coal mines implemented in the United States as models, a program of technology transfer should be aimed specifically at Canada's smaller mining enterprises. Existing agencies such as MAC, CIM, and particularly the provincial mining associations (which include the smaller firms among their members) could be used as a nucleus, and organizations such as CIM local branches could help with local presentations and contacts.

5. **Industry, universities and governments should actively cooperate to promote understanding and better communication of technology-related issues,** through:
   - increased industry input to government decision-making processes related to mineral industry R&D and technology;
   - encouragement of increased cooperation between companies, in all industry sectors and within and beyond Canada, in technology development, commercialization and transfer;
   - establishment of university/industry/government sponsored management and technical courses.

There is clearly a need for improved understanding of the technical challenges facing the mineral industry. Unlike the mineral industries in Australia, Europe and South Africa, the Canadian industry has demonstrated little willingness to develop significant levels of intra-industry cooperation in this area, through, for example, industry-wide R&D organizations. There is a need for increased understanding of the strategic and management issues related to managing technology. As noted earlier, industry has little control over government programs in support of their industry in this key area. There is a need for joint leadership from industry, university, and government in developing the necessary understanding and cooperation.

6. **CANMET should assist the CIM and other mineral-related scientific and technical bodies in making their unpublished technical papers known to the industry, through the MINPROC and MINTEC data bases.**

The MINTEC and MINPROC data bases are an existing vehicle that could be used for publication of titles and key words identifying CIM papers that are not published in the CIM Bulletin or Special Publications. The same could be done for the papers presented at all kinds of mineral-related technical meetings. Provision would have to be made for providing complete copies of the papers on request. This is a relatively small suggestion, but one that could be implemented quickly, at relatively little cost and with immediately useful effects, including both increased circulation of technical papers and increased industry use of the data bases.

STRATEGIES FOR MEDIUM-TERM RESULTS

These are intended for implementation over 1-5 years, starting immediately, and are aimed at medium-term results in increasing Canadian technological capability.

1. **A target of 1.5 to 2 percent of revenues to be spent annually on technical development in the mineral industries should be attained by 1990.**

Technical development in the mineral industries is presently underfunded, both in an absolute sense and relative to spending in similar technically-intensive industries. A target of 1.5 to 2 percent of

revenues, to be spent on all aspects of technical development (applied research, development, commercialization and technology transfer) would allow a substantial increase in Canadian capabilities. This should be considered an order-of-magnitude suggestion, rather than a prescription or an upper limit. Obviously, the present 0.6 percent is too low; 10 or 15 percent would not make sense in a resource industry, considering the possible returns on R&D investment. This range - 1.5 to 2 percent - would be a solid improvement, and adequate for the purpose if effectively managed. The federal government should provide an incentive for the private sector by matching spending on, say, a dollar-for-dollar basis, although industry will need a period of time to work up to the recommended level of support. This funding should be in addition to strong support for basic R&D, which has a totally different set of criteria for evaluation and justification.

2. **Increased emphasis should be placed on the development of new and improved exploration and mining technologies, and on new product development, which are areas of great need and of great opportunity.**

Exploration and mining technologies currently do not receive R&D funding corresponding to their importance to the mineral industry and to Canada. The federal government should direct a greater portion of its applied R&D funding towards these earlier stages in the mineral processing chain, and industry should increase its support of these areas as well. In metallurgy, the greatest R&D opportunities appear to lie in the development of new high-value-added products with good market potential.

3. **Industry and governments should provide funding and support for the development of increased mining equipment manufacturing capabilities in Canada. The mineral industry should also become actively involved in domestic equipment manufacturing.**

A major barrier to innovation at present is the lack of Canadian suppliers with the size and scope of activities to work with the mining industry on major technical innovations which are embodied in new equipment and processing systems. This sector falls between two stools in terms of federal government support, being specifically excluded from EMR's mandate and effectively excluded from DRIE's support programs. Government grants and contracts for all stages of joint technical development projects between promising equipment firms and mining companies

would provide strong support for an increased domestic capability in an area with export potential far beyond domestic demand. The mining industry has also kept itself at a distance from equipment manufacturers in the past. Industry support should take the form of joint ventures, forward integration, cooperation in provision of opportunities for piloting and demonstration, and other measures designed to identify needs, share development risk, and improve technology transfer.

4. **Positive tax incentives should be offered by the federal government for all industry activities related to mineral technology development.**

Traditional tax incentives have not been sufficient to stimulate the required levels of research and development in Canada's mineral industry. At present, in fact, many tax incentives are meaningless, since few companies are taxable; this situation could prevail for some time. A number of novel approaches could be tried in this area. Flow through shares, similar to those for mineral exploration (but more tightly regulated than those recently offered for research and development), could be effective, since the industry is familiar with this vehicle. In addition, the federal government should recognize that much innovation in the mineral industries takes place in the workplace, and allow appropriate deductions for these similarly risky activities even when the development and demonstration phases are part of the production process.

5. **Government grants and contracts for applied research and development and technological innovation made to universities and private sector firms should be matched by a significant industry contribution.**

Much of the applied R&D work being carried out at present appears to have little commercial value to the industry, either because it is not relevant, or because it is not commercialized. To confirm industry's commitment to such activities, the federal government should require some corresponding contribution from individual firms or their technical cooperative associations, as soon as economic conditions, cash flows, and management attitudes permit. Both government and industry tied grants should be project-specific, and initiatied by industry.

6. **Government research and development support programs for industry should favour joint ventures among companies, and include universities and end users whenever possible.**

This will help to overcome the isolation and lack of "critical mass" that handicap some R&D efforts. HDRK and NiDI are positive industry steps in the direction of joint ventures, but both are experiencing difficulties in obtaining federal financial support.

7. **Government support for applied research and development in universities should favour interdisciplinary studies and industry participation.**

Interdisciplinary approaches will be required for major breakthroughs in fields such as biohydrometallurgy, process control, new approaches to rock fragmentation, robotics, etc. The NSERC evaluation criteria seem to discourage this approach at present, although its support of mining chairs and centres of strength is a positive step. NRC's PILP program already favours projects involving producers, users, and university and government researchers.

8. **An NSERC committee (or committees) should be established for funding of basic and applied university research in mining-related areas.**

A clear distinction should be made between basic and applied studies. Especially for applied proposals, the committee should include some industry researchers, and cover fields including deposit delineation, mining, processing, and metallurgy. Proposals should be encouraged to be interdisciplinary, and to include industry participation in the research. Basic proposals should have a separate funding program, with predominantly academic criteria and evaluation.

STRATEGIES FOR LONG-TERM RESULTS

These are for implementation over 1-10 years, <u>starting immediately</u>, and aimed at long-term goals that will lead to leadership in competitive position for production of a broad range of minerals and mineral products, through Canadian strength in basic R&D in earth sciences and mineral-related fields, as well as Canadian leadership in mineral R&D and technology capability.

1. **The basis for long-term science-based breakthrough technologies should be established by supporting existing and new bases of expertise, both in basic research and mineral technology at**

Canadian universities, and in applied research in university, government, and private sector facilities.

For the Canadian mineral industry to maintain a position of world leadership in selected areas of technology by the end of the century, the fundamental research programs will have to be in place by the end of the current decade. Industry and government should cooperate in identifying objectives and providing the required funding. In the initial years of this program the required funding will be relatively modest, since basic and applied research are relatively low-cost activities, compared with demonstration and commercialization. There should be an emphasis on joint and cooperative ventures, and on cooperation between universities. As noted previously, the establishment of university chairs and centres of strength in mining is a positive move toward establishing research capability in universities.

2. **The Canadian mineral industry should establish a joint technical organization similar to AMIRA or the South African Chamber of Mines.**

Industry collaboration on a broad scale is needed, and some steps in this direction have already been taken by the Mining Association of Canada and the Ontario Mining Association. Industry-wide R&D organizations are becoming commonplace in the United States, where mature industries are threatened by intense offshore competition, and the Canadian pulp and paper industry in Canada provides a model as well. An organization is needed which can coordinate research and development throughout the industry, focus R&D funding from all sources, establish cooperative programs, and ensure efficient diffusion and transfer of new technology throughout the sector. It would also help to insulate long-term development projects from the short-term economic vagaries of the industry.

3. **Government should take immediate steps to increase the role of industry and universities in decision-making that affects government in-house activities and funding programs for applied R&D and technology.**

The long-term goal should be a sharing of the effective decision-making power in applied R&D and technology activities with the industry, as the potential end-users, and with universities as the principal source of expertise in basic research as well as participants in applied work. The shared responsibility could follow the model of AMIRA in Australia,

or it could take the form of establishing a governing council for agencies such as CANMET and NSERC with strong and possibly majority representation from industry and universities. This would require a move away from traditional departmental status.

An interim alternative for CANMET could be an increased emphasis on projects initiated by industry (or its joint research organizations) and funded jointly by government and industry. A "not fully funded" basis for government's contribution would be much simpler to initiate and operate than a "matching funds" basis. A distinction could be made between single-company confidential contracts and long-term higher-risk cooperative industry contracts in the public domain.

4. **Governments should take steps to minimize the problems of overlapping and sometimes conflicting departmental jurisdiction over mineral-related subjects.**

While political pressures and overlapping interests of various economic sectors will prevent complete elimination of this problem, some consolidation and an improved focus on the technology needs of the mineral industry would be possible and constructive. Ad hoc cooperation of the sort achieved by the Nonferrous Smelting Working Group provides one possible model, and the Quebec government's recent reorganization of mining-related responsibilities provides another.

5. **Long-term R&D and innovation efforts should focus on the development of methods and equipment based on currently emerging technologies, as well as the more traditional areas.**

Emerging technologies should not necessarily be R&D priorities for the mineral sector, but should be carefully watched for technology transfer opportunities. They include a wide range of disciplines and interdisciplinary studies not directly related to mining, such as biotechnology (for biohydrometallurgical methods), information technology (for data analysis, for process and operations design, and for automation and control of processes) robotics (for automation and remote-controlled equipment), nuclear physics (for sensing and measuring devices), etc.

6. **Industry, academic, and government decision-makers should stay informed on long-term trends in the mineral industry, and work together to adjust the focus of R&D and technology efforts as required.**

Structural changes in mineral supply and demand over the years will affect Canada's long-term comparative advantage, and dictate shifts in emphasis in terms of minerals sought, stage of processing appropriate in Canada, product quality and diversity, etc. Government sources of information such the Mineral Policy Sector of EMR should maintain close contacts with academics, and place emphasis on anticipation of trends. They should also continue to keep close contacts with industry, in Canada, in competing countries, and in existing and potential mineral markets. It must be remembered, however, that R&D is a long-term process and cannot be turned on and off capriciously, or within arbitrary time limits.

APPENDIX A. MINERAL INDUSTRY DATA

Table A1

VALUE OF MINERAL PRODUCTION OF CANADA, BY CLASSES, SELECTED YEARS 1945-1985
($ million)

	Metals	Non-metals[1]	Structural Materials	Coal	Total[2]
1945	317	40	48	68	473
1950	617	95	132	110	954
1955	1,008	145	228	94	1,475
1960	1,407	198	323	75	2,001
1965	1,908	327	434	76	2,745
1970	3,073	481	450	86	4,090
1975	4,794	939	960	586	7,280
1976	5,073	1,162	1,103	607	7,946
1977	5,988	1,362	1,249	610	9,209
1978	5,698	1,478	1,508	779	9,463
1979	7,951	1,868	1,646	860	12,325
1980	9,697	2,532	1,669	932	14,830
1981	8,684	2,707	1,769	1,073	14,368
1982	6,874	1,979	1,730	1,294	12,093
1983	7,238	1,903	1,702	1,300	12,314
1984	8,670	2,366	1,951	1,795	14,782
1985	8,547	2,434	1,991	1,884	15,282

Source: 1945-83, Statistics Canada, Catalogues 26-201 and 26-202; 1984-85, Canadian Mining Journal, February 1986.

[1] Includes peat, for 1965-85.
[2] Including "other minerals" for 1981-85, which are not shown elsewhere in the table.

Table A2

VALUE OF CANADIAN MINERAL PRODUCTION BY STAGE OF FABRICATING, 1979-82
($ million, current)

	1979	1980	1981	1982
Mining[a]	12,928	15,892	14,970	12,780
Smelting and Refining	3,920	4,978	4,529	4,222
Primary Metals	9,791	10,397	11,424	9,218
Metal Fabricating	11,454	12,808	13,620	12,514
Total: Mineral Sector[b]	38,092	44,074	44,543	38,733

Source: Statistics Canada, Catalogue 61-213.

[a] Mining (only) includes non-metallics.
[b] Excluding non-metallic mineral manufacturing.

Table A3

VALUE OF MINERAL PRODUCTION, BY PROVINCE, BY COMMODITY, 1985
(in 000's of $'s)

	Nfld.	P.E.I.	N.S.	N.B.	Quebec	Ontario	Manitoba	Sask.	Alberta	B.C.	Yukon	N.W.T.	Canada
Metals													
Antimony				3,344						4,233			8,577
Bismuth				3,641		35	7			893	10	68	4,344
Cadmium				304	423	3,109	906	38		872	9	756	6,111
Cobalt						79,899	12,139						91,737
Columbium					x								x
Copper				13,031	136,365	864,189	123,906	9,299		399,697			1,445,357
Gold				3,566	497,065	449,906	39,231	2,949	117	99,604	43,000		1,197,951
Iron Ore	835,633				x	x				3,195			1,548,783
Iron, result					x								x
Lead				42,362		2,427	294			61,429	977	44,995	152,384
Molybdenum					2,201					73,999			76,290
Nickel						988,389	246,083						1,234,961
Platinum group						x	x						x
Selenium					3,148	3,263	972	172					6,556
Silver				52,215	13,836	126,497	9,734	1,335		101,485	12,975	9,615	337,362
Tantalum							3,945						3,945
Tellurium					304	121	100	18					543
Tin										1,796			1,796
Tungsten				x								x	x
Uranium							519,479			438,191			957,660
Zinc	37,642			392,875	81,571	341,732	99,356	9,253		135,441	41	341,933	1,318,824
Total Metals	873,275			416,240	1,388,313	3,275,941	537,133	466,995	117	1,979,332	56,710	577,754	8,548,740
Nonmetals													
Asbestos	39,442				241,954					96,779			852,275
Barite	382		1,779			1,500				2,894			6,235
Gemstones					110					1,041			1,151
Gypsum	5,337		52,216			18,933	2,995			4,349			89,321
Magnesitic dolomite & barite					6,975					3,516			10,491
Nepheline Syenite						18,983							18,983
Peat	49	685	939	13,154	18,488	612	12,484	1,750	10,164	150			58,473
Potash				x				x					842,954
Quartz	1,853		x	x	x	11,930	2,960	x	4,790	2,913			44,110
Salt			x	x	x	130,684		38,817	18,218				225,995
Soapstone, talc, pyrophyllite					3,987	9,181							13,683
Sodium Sulphate								29,995	3,482				33,387
Sulphur, in smelter gas				11,638	12,935	35,948	42			2,199	88	3,968	65,992
Sulphur elemental						83		636	951,763	29,174			981,655
Total Nonmetals	39,538	685	96,418	38,935	310,341	230,893	18,188	672,736	986,327	138,015	88	3,968	2,434,737
Coal			160,000	29,000				125,100	485,500	1,101,700			1,984,100
Structural Materials													
Clay products	1,150		7,750	4,335	21,967	91,725	2,150	4,958	7,550	3,000			144,487
Cement	9,462		22,094	15,134	199,200	292,225	23,148	16,788	118,779	77,230			780,050
Lime				5,340	18,250	90,115	5,725		18,385	7,300			137,043
Sand and gravel	11,350	1,550	21,300	9,700	69,919	187,488	23,150	26,275	100,000	76,835	1,235	33,350	561,254
Stone	3,335		21,250	11,130	143,574	151,887	8,635		2,334	38,325		796	378,155
Total Structural Materials	24,297	1,550	72,394	45,619	430,938	793,352	91,808	47,194	247,958	201,489	1,235	34,145	1,999,989
Total Other Minerals			4,587	199,248	176,971	9,068	2,329	488		1,818		33,478	426,189
Grand Total	987,110	2,235	327,984	550,691	2,236,841	4,475,057	647,188	1,304,294	1,583,383	2,510,472	58,933	649,337	15,383,755

Source: Canadian Mining Journal, February 1986.

x = not available for reasons of confidentiality

Table A4

MINERAL SECTOR CONTRIBUTION TO GROSS PROVINCIAL[a] PRODUCT, 1982-83, CURRENT PRICES
(percent)

Province	1977[b]	1982	1983[b]
Newfoundland	34.2	14.5	14.3
Prince Edward Island	0.4	0.2	0.1
Nova Scotia	3.4	3.6	2.9
New Brunswick	7.8	7.9	7.4
Quebec	3.8	2.8	2.4
Ontario	4.0	2.6	1.9
Manitoba	7.3	3.5	3.7
Saskatchewan	16.1	7.5	6.5
Alberta	39.1	2.8	2.4
British Columbia	7.4	5.2	4.9

Source: Mining Association of Canada, Facts and Figures, 1984.

p = preliminary
[a] Information for Yukon and Northwest Territories not available from MAC figures.
[b] 1977 figures include oil and gas, which inflates the contribution for Alberta and Saskatchewan in particular.

Table A5

MINERAL SECTOR CONTRIBUTION TO GROSS CANADIAN DOMESTIC PRODUCT, 1979-84
(1971 constant prices)
(percentage)

	1979	1980	1981	1982	1983	1984[a]
Mining[b]	1.7	1.8	1.6	1.4	1.5	1.6
Smelting & Refining	0.4	0.5	0.5	0.4	0.5	0.5
Primary Metals	1.4	1.2	1.2	1.0	1.0	1.2
Metal Fabricating	1.9	1.8	1.8	1.5	1.4	1.4
Total	5.2	5.3	5.0	4.3	4.4	4.7

Source: Statistics Canada, Catalogue 61-213, 61-005.

[a] August 1984 estimate
[b] Mining (only) includes non-metallics.

Table A6

CANADA, INDEXES OF GROSS DOMESTIC PRODUCT BY INDUSTRY (1971 = 100)

Industry or Industry Group	1984 Average	1985 Average	Percentage Change
Gross domestic product	150.0	156.4	4.2
Primary industries			
Agriculture	115.0	117.2	1.9
Forestry	125.4	124.6	-0.6
Fishing and trapping	109.4	112.3	2.7
Mines, quarries and oil wells	110.7	112.1	1.3
Metal mines	81.0	79.0	-2.5
Placer and gold quartz mines	107.9	121.6	12.7
Iron mines	59.0	60.7	2.8
Other metal mines	85.4	81.6	-4.5
Mineral fuels	128.5	132.5	3.1
Coal mines	329.3	347.5	5.5
Crude Petroleum and Natural Gas	113.4	116.3	2.6
Nonmetal mines	116.0	105.1	-9.4
Asbestos mines	38.8	39.1	0.7
Secondary Industries			
Manufacturing	138.8	145.2	4.6
Nondurable manufacturing	137.2	141.6	3.2
Petroleum and coal products industries	86.4	84.8	-1.9
Durable manufacturing	140.3	148.6	5.9
Primary metal industries	122.7	124.6	1.5
Iron and steel mills	122.6	124.3	1.4
Steel pipe and tube mills	101.5	106.9	5.2
Iron foundries	111.7	111.0	-0.7
Smelting and refining	119.6	122.2	2.2
Nonmetallic mineral products industries	111.9	119.5	6.8
Cement manufacturers	97.6	108.4	11.1
Ready-mix Concrete manufacturers	98.6	105.4	6.8
Construction industry	106.1	112.3	5.5
Transportation, storage, communication	178.6	185.5	3.9
Electric power, gas and water utilities	200.7	211.2	5.2
Trade	166.5	177.9	6.8
Finance, insurance, real estate	176.0	185.2	5.3
Community, business and personal service	154.2	159.7	3.6
Public administration and defence	140.7	141.8	0.8

Source: EMR, The Canadian Mineral Industry Monthly Report, February 1986, table 1.

Table A7

VALUE OF EXPORTS OF CRUDE MINERALS AND FABRICATED PRODUCTS FROM CANADA, 1979-83
($ millions)

	1979	1980	1981	1982	1983
Ferrous					
Crude material	1,469.5	1,342.9	1,540.0	1,098.3	1,054.3
Fabricated material	1,947.6	2,358.0	2,664.9	2,299.2	2,011.6
Total	3,417.1	3,701.1	4,205.0	3,397.5	3,065.9
Nonferrous					
Crude material	2,425.1	2,866.6	2,544.0	2,088.8	1,845.9
Fabricated material	3,807.1	6,273.8	5,615.6	4,977.9	5,624.5
Total	6,232.1	9,140.4	8,159.6	7,066.7	7,470.5
Nonmetals					
Crude material	1,715.3	2,305.0	2,618.7	2,171.1	2,103.5
Fabricated material	455.9	412.5	439.7	409.3	424.8
Total	2,171.2	2,717.5	3,058.3	2,580.5	2,528.3
Coal					
Crude material	785.0	923.0	1,026.0	1,184.0	1,210.0
Fabricated material[a]	377.0	464.8	528.4	507.0	563.2
Total	1,212.0	1,398.8	1,675.4	1,776.0	1,876.2
Total Minerals and Products					
Crude material	6,394.9	7,437.5	7,728.7	6,542.2	6,213.7
Fabricated material	6,587.6	9,509.1	9,248.6	8,193.4	8,624.1
Total	12,982.5	16,946.6	16,977.3	14,735.6	14,837.8
Crude Materials as % of Exports, all Products	9.73	9.77	9.23	7.74	6.90
Crude and Fabricated Minerals and as % of Exports all Products	19.8	22.3	20.3	17.4	16.3

Source: Department of Finance, Economic Review, April 1984, Table 67, p. 204 and Department of Energy, Mines and Resources Canada, Canadian Mineral Industry Monthly Report, April 1986.

[a] Crude estimate; obtained by arbitrarily assuming that 20 percent of fabricated fuels are coal-based.

p Preliminary

Table A8

CRUDE AND FABRICATED EXPORTS IN THE PRIMARY RESOURCE SECTOR, 1979-84
($ million, current)

Industry	1979	1980	1981	1982	1983	1984
Agriculture	6,378	8,186	9,281	9,746	9,991	10,627
Fishing/Trapping	1,271	1,265	1,494	1,591	1,566	1,591
Forestry	11,735	12,731	12,865	11,942	13,136	15,530
Mineral Sector	11,937	15,603	15,053	13,514	13,450	16,638
Petroleum	7,477	9,207	9,549	10,107	10,234	11,647
Resource Sector	38,798	47,072	49,042	46,900	48,385	56,033

Table A9

EMPLOYMENT IN THE CANADIAN MINERAL INDUSTRY

	1979	1980	1981	1982	1983[a]	1984[b]
Mining:						
Thousand	91.9	95.6	94.7	82.5	84.5	81.7
Percent	0.88	0.89	0.86	0.78	0.79	0.74
Smelting & refining:						
Thousand	33.2	33.2	32.5	25.5	30.2	29.4
Percent	0.32	0.31	0.30	0.24	0.28	0.27
Primary metals:						
Thousand	92.2	90.2	90.8	69.3	75.7	80.4
Percent	0.89	0.84	0.83	0.65	0.71	0.73
Metal fabricating:						
Thousand	129.5	125.9	116.7	95.1	159.2	134.5
Percent	1.25	1.18	1.06	0.89	1.48	1.22
Non-metallic mineral manufacturing:						
Thousand	49.0	45.9	44.4	35.3	48.5	49.6
Percent	0.47	0.43	0.43	0.33	0.45	0.45
Total mineral sector:						
Thousand	359.1	390.8	379.1	307.7	398.1	375.6
Percent	3.8	3.7	3.5	2.2	3.7	3.4

Source: Derived from Statistics Canada, Catalogue 72-002

[a] August 1983 data
[b] August 1984 data

Table A10

COMPARATIVE WAGE RATES, ALL WAGE EARNERS IN INDUSTRY LISTED, WEEKLY EARNINGS, 1979-84
(current dollars)

	1980	1982	1984	1986
Metal mining	434.15	551.01	627.83	692.33
Coal mines	463.55	490.67	679.84	741.08
Non-metal mines	412.99	464.31	564.88	606.63
Quarries & sand pits	329.66	384.43	473.75	513.70
Smelting & refining	402.93	532.27	631.67	648.31
Primary metals (includes smelting & refining)	388.42	476.76	597.12	629.53
Metal fabricating	332.89	396.96	461.20	483.19
Non-metallic Mineral Manufacturing	358.79	416.40	499.95	556.37
Forestry	n/a	n/a	516.08	564.72
Manufacturing (total)	323.27	389.29	463.45	499.80
Construction	457.24	560.24	491.28	497.48

Source: Statistics Canada, Catalogue 72-002.

[a] August 1983 data.
[b] August 1984 data.

Table A11

NUMBER OF PRODUCING MINES IN CANADA, AS OF JANUARY 1984 BY MAIN MINERALS PRODUCED

	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Y.T.	N.W.T.	Total
Asbestos	1				6					1			8
Coal			7	6				5	21	6	0		45
Copper					5					5			10
Copper-molybdenum[2]										6			6
Copper-zinc[2]					5	5	11	1		1			23
Gold[3]				1	16	13				5		5	40
Gypsum	1		4	1		3	1			1			11
Iron ore[4]	2				3	4				1			10
Lead-zinc[2]	1			2						2	1	3	9
Limestone	1		4	5			2		8	4			24
Molybdenum				1						1			2
Nickel-copper[2]						11	3						14
Potash				1				10					11
Salt			2	1	1	2		2					8
Silica	1		2	1	6	1	2			1			14
Sodium sulphate								6					6
Uranium						4		3					7
Others[5]	6		3		6	9	1	1		4		2	32
Total	13	0	22	19	48	52	20	28	29	38	1	10	280

Source: The Mining Association of Canada, Mining Facts and Figures, 1984.

[1] Producers of clay products and construction materials not shown.
[2] Most non-ferrous base metal mines yield varying quantities of precious metals.
[3] Most of the lode gold mines as shown also produce some silver.
[4] Includes byproduct producers.
[5] Includes one each of: amethyst (Ont.), bentonite (Sask.), zinc (Nfld.), copper-gold (Y.T.), magnesium (Ont.), iron-titania (Que.), mica (Que.), niobium (columbium) (Que.), pyrophyllite (Nfld.), tantalum (Man.), serpentine (Ont.), tungsten (N.W.T.), brick-shales (Nfld.), silver-copper (N.W.T.); two each of: nepheline syenite (Ont.), talc (Ont.), silver (B.C.); three each of: silver-cobalt (Ont.), magnesitic dolomite (2 N.S., 1 Que), soapstone (Que.); five of barite (2 B.C., 1 Nfld., 1 Ont., 1 N.S.).

Table A12

MAJOR SMELTERS AND REFINERIES IN CANADA, 1985

	Location	Product	Facility Type	Annual Rated Capacity (Feedstock)
Alcan	Vaudreil, P.Q.	alumina	refinery	1,225,000 tons
	Arvida, P.Q.	aluminum	smelter	432,000 tons
	Beauharnois, P.Q.	aluminum	smelter	47,000 tons
	Ile Maligne, P.Q.	aluminum	smelter	73,000 tons
	Shawingigan Falls, P.Q.	aluminum	smelter	84,000 tons
	Grande Baie, P.Q.	aluminum	smelter	171,000 tons
	Kitimot, B.C.	aluminum	smelter	268,000 tons
Canadian Reynolds Metals Co. Ltd.	Baie Comeau, P.Q.	aluminum	smelter	300,000 tons
Falconbridge Ltd.	Falconbridge, Ont.	nickel-copper	smelter	620,000 tons
Gaspe Division (Noranda Inc.)	Murdochville, P.Q.	copper	smelter	300,000 tons
	Murdochville, P.Q.	sulphuric acid		160,000 tons
Hudson Bay Mining & Smelting Co. Ltd.	Flin Flon, Man.	copper	smelter	375,000 tons
Inco Ltd.	Copper Cliff, Ont.	copper-nickel	smelter	2,400,000 tons
	Thompson, Man.	nickel and copper	smelter	1,100,000 tons
Kidd Creek Mines Ltd.	Timmins, Ont.	copper	smelter	65,000 tons
Noranda Inc.	Noranda, P.Q.	copper	smelter	1,000,000 tons
Brunswick Mining & Smelting Corp. Ltd. (Noranda Inc.)	Belledune, N.B.	lead	refinery & smelter	70,000 tons
	Belledune, N.B.	silver dore		110 tons
Cominco Ltd.	Trail, B.C.	lead	smelter & refinery	150,000 short tons refined

Table A12 (continued)

MAJOR SMELTERS AND REFINERIES IN CANADA, 1985

	Location	Product	Facility Type	Annual Rated Capacity (Feedstock)
Chromasco, a division of Timminco Ltd.	Haley, Ontario	magnesium	smelter	66,000 tons
	Haley, Ontario	calcium metal	smelter	2,000 tons
	Haley, Ontario	strontium	smelter	200 tons
	Beauharnois, P.Q.	quartz	smelter	60,000 tons
	Beauharnois, P.Q.	coke	smelter	15,000 tons
	Beauharnois, P.Q.	coal	smelter	20,000 tons
	Beauharnois, P.Q.	steel scrap	smelter	10,000 tons
	Beauharnois, P.Q.	woodchips	smelter	16,000 tons
	Beauharnois, P.Q.	limestone	smelter	5,000 tons
	Beauharnois, P.Q.	manganese	smelter	30,000 tons
	Beauharnois, P.Q.	silicomanganese	smelter	9,000 tons
Endako Mines Division (Placer Develop. Ltd.)	Endako, B.C.	molybdenum	roaster	24,000,000 lbs.
QIT Fer et Titane Inc.	Sorel, P.Q.	titaniumslag and metallic iron	smelter	2,000,000 tons
CCR Divison (Noranda Inc.)	Montreal, P.Q.	copper, copper sulphate, precious metals, selenium, tellurium	refinery	410,000 tons
Inco Ltd.	Sudbury, Ont.	copper, gold, silver, selenium tellurium, semi-refined platinum group metals, nickel sulphate	refinery	198,000 tons
Kidd Creek Mines Ltd.	Timmins, Ont.	copper	refinery	71,000 tons

Table A12 (continued)

MAJOR SMELTERS AND REFINERIES IN CANADA, 1985

	Location	Product	Facility Type	Annual Rated Capacity (Feedstock)
Royal Canadian Mint	Ottawa, Ont.	gold	refinery	12,000,000 oz. refined
Johnson Matthey	Brampton, Ont.	gold	refinery	not specified
Inco Ltd.	Copper Cliff, Ont.	nickel pellets	refinery	45,000 tons
	Copper Cliff, Ont.	nickel powder	refinery	12,500 tons
	Port Colborne, Ont.	nickel	refinery	not specified
Sherritt Gordon Mines Ltd.	Fort Sask., Alberta	nickel	refinery	22,000 tons refined
	Fort Sask., Alberta	cobalt	refinery	1,000 tons refined
	Fort Sask., Alberta	nitrogen & phosphate	refinery	630,000 tons refined
Agnico-Eagle Mines Ltd.	Cobalt, Ont.	silver	refinery	160-180 tons of concentrate per month
Cominco Ltd.	Trail, B.C.	silver	refinery	not specified
Johnson Matthey Ltd.	Brampton, Ont.	silver	refinery	not specified
Eldorado Resources Ltd.	Port Hope, Ont.	UF_6	refinery	9,000 tons output
	Port Hope, Ont.	UO_2	refinery	2,500 tons output
Canadian Electrolytic Zinc Ltd.	Valleyfield, P.Q.	zinc, cadmium, sulphuric acid	refinery	230,000 tons refined
Cominco Ltd.	Trail, B.C.	zinc; cadmium, indium	refinery	300,000 tons refined
Kidd Creek Mines Ltd.	Timmins, Ont.	zinc	refinery	127,000 tons
Hudson Bay Mining & Smelting Co. Ltd.	Flin Flon, Man.	zinc	refinery	82,000 tons

Table A12 (continued)

MAJOR SMELTERS AND REFINERIES IN CANADA, 1985

	Location	Product	Facility Type	Annual Rated Capacity (Feedstock)
Algoma Steel Corp. Ltd.	Sault Ste. Marie, Ont.	steel		not specified
Dofasco Inc.	Hamilton, Ont.	steel		4,500,000 ingot tons produced
QIT Fer et Titane Inc.	Sorel, P.Q.	special pig iron		600,000 tons produced
Stelco Inc.	Hamilton, Ont.	sinter		762,000 tons
	Hamilton, Ont.	pig iron		3,810,150 net tons
	Hamilton, Ont.	coke		2,154,550 net tons
	Hamilton, Ont.	crude steel		5,261,650 net tons
	Nanticoke, Ont.	coke		585,900 net tons
	Nanticoke, Ont.	crude steel		1,587,000 net tons
	Edmonton, Alberta	crude steel		300,000 net tons
	Contrecoeur, P.Q.	crude steel		340,000 net tons
Sydney Steel Corp.	Sydney, N.S.	basic iron		875,000 net tons
	Sydney, N.S.	raw steel		1,000,000 net tons produced
Sidbec-Dosco Inc.	Contrecoeur, P.Q.	steel		1,100,000 tons
	Longueuil Works, P.Q.	steel		300,000 tons
	Montreal Works, P.Q.	steel		150,000 tons

Source: Canadian Mines Handbook, 1985-86.

Table A13

TOTAL R&D EXPENDITURES, CANADA, 1978-82
($ millions)

Industry Sector	1978	1979	1980	1981	1982	Increase Factor 1978-82
SELECTED RESOURCES						
Mines	18	21	31	46	49	2.7
Gas & oil wells	38	97	110	159	322	8.5
SELECTED MANUFACTURING						
Primary metals (ferrous)	16	19	21	23	25	1.5
Primary metals (nonferrous)	50	60	85	74	75	1.5
Metal fabricating	12	15	19	23	29	2.4
Non-metallic mineral product	6	7	9	11	15	2.5
Rubber, plastic products	11	14	16	17	21	1.9
Wood-based industries	36	53	65	80	76	2.1
Business machines	18	27	43	55	79	4.4
Communications equipment	168	210	257	365	536	3.2
Scientific and professional equipment	9	10	14	18	24	2.7
TOTAL MANUFACTURING[1]	791	984	1,213	1,556	1,915	2.4
TOTAL ALL INDUSTRIES[1]	1,007	1,269	1,564	2,004	2,572	2.55

Source: Statistics Canada, "A Framework for Measuring Research and Development Expenditures in Canada", March 1984, p. 23.

[1] Totals include a number of categories that have been omitted from the table.

Table A14

R&D INTENSITY IN SELECTED U.S. INDUSTRIES FOR 1960, 1970 AND 1981
(total funding as a percent of net sales)

Industry	R&D Intensity		
	1960	1970	1981
Aircraft and parts	22.5	16.2	15.3
Scientific measuring Instruments	8.6	3.5	9.2
Other instruments	5.3	6.6	7.8
Electrical equipment	11.2	7.3	6.8
Communication equipment and components	13.1	8.2	8.9
Machinery	4.7	4.0	5.2
Office and computing machinery	n.a.	n.a.	11.7
Other machinery	n.a.	n.a.	2.5
Motor vehicles and other transportation equipment	3.0	3.5	4.1
Chemicals	4.5	3.9	3.8
Industrial chemicals	5.7	4.2	3.5
Drugs	4.8	6.7	6.4
Other chemicals	2.2	1.8	2.1
Rubber products	2.0	2.3	2.5
Fabricated metal products	1.3	1.2	1.4
Nonferrous metals	1.0	1.0	1.2
Paper and allied products	0.7	0.9	1.1
Lumber, wood products, furniture	0.6	0.8	0.9
Ferrous metals	0.6	0.7	0.8
Petroleum refining	1.0	1.0	0.7
Textiles and apparel	0.6	0.5	0.4

Source: National Science Foundation, quoted in P.E. Queneau, "Innovation and the Future of the American Primary Metal Industry", Materials & Society, vol. 9, no. 2, 1985, p. 229.

APPENDIX B MINING EQUIPMENT INFORMATION

Table B1

CANADIAN MANUFACTURING CAPABILITIES AND DEFICIENCIES[1] FOR SPECIFIC CATEGORIES OF MINING RELATED EQUIPMENT (1979)

Open Pit Mining	
Deficiencies in Canadian Capability	Canadian Capability 50-75%
- large rotary drill rigs (pneumatic and hydraulic	- trucks and service vehicles
- large rotary drill bits	- air track drills
- large mobile	
- track and rubber tire dozers	Canadian Capability 75-100%
- large front end loaders	
- large electric and diesel shovels	- graders
- draglines	- loaders (special)
- oversized tires	- pumps (special)
- pumps (special)	- conveyors
- rockbreakers (special)	- drill rods
- train feeders	

1. A "deficiency" was indicated when the Canadian capability to produce particular type of equipment was estimated to be less than 50 percent of domestic demand.

Table B1 (continued)

CANADIAN MANUFACTURING CAPABILITIES AND DEFICIENCIES FOR SPECIFIC CATEGORIES OF MINING RELATED EQUIPMENT

Underground Mining	
Deficiencies in Canadian Capability	Canadian Capability 50-75%
- long hole drills	- crawler drills
- loaders (special)	- boom drills
- mucking machines	- LHD diesel
- mine trolleys and locomotives	- compressors
- pumps (special)	- scraper hoists
- rockbreakers (special)	- roofbolters
- diesel generators	- raise equipment
- lamps (special)	
- hoists (special)	Canadian Capability 75-100%
	- ore cars
	- slushers
	- tuggers
	- jackleg drills
	- long tom drills
	- jaw crushers
	- dust collectors
	- fans (special)
	- pumps (special)
	- boilers
	- loading pockets
	- bits
	- explosive loaders
	- chain blocks and hoists
	- lamps (special)
	- diamond drills
	- hoists

Table B1 (continued)

CANADIAN MANUFACTURING CAPABILITIES AND DEFICIENCIES FOR SPECIFIC CATEGORIES OF MINING RELATED EQUIPMENT

Concentrating and Milling	
Deficiencies in Canadian Capability	Canadian Capability 50-75%
- impactors	- stacker
- gear drivers (special)	- cleaning screens
- sieves	- pumps (special)
- classifier screens disc filters	- instrumentation filters
- cyclones (specials)	- grinding mills
- spirals	- crushers
- dryers (special)	- flotation cells
- control laboratory equipment	- presses
- instrumentation (monitoring systems for flow levels and weights)	- vibrating screens
- weigh balance equipment	- dryers (special)
- pumps (special)	- knife gates
- bearings (special)	- trolley crane
- car dumpers	- X-ray analyzers
- couplings (special)	- belt reels
	- bearings and seals
	- centrifuges
	- cyclones
	- thickeners
	- loadout bins
	- substantions
	- electric equipment
	- electric motors

Table B1 (continued)

CANADIAN MANUFACTURING CAPABILITIES AND DEFICIENCIES[1] FOR SPECIFIC CATEGORIES OF MINING RELATED EQUIPMENT

Smelters (Standard)	
Deficiencies in Canadian Capability	Canadian Capability 75-100%
- converters (special)	- substations
- electrostatic precipitators	- transformers
- casting machines (special)	- elevators
- fans, scrubbers (special)	- electric motors
- instrumentation (special)	- tanks
- drumming equipment (special)	- trippers
- sampling equipment (special)	- feeders
	- converters

Smelters (Planned)	
Deficiencies in Canadian Capability	Canadian Capability 75-100%
- pulverizers	- tuyers
- pumps, blowers, valves (special)	- storage tanks
- centrifuges (special)	- valves (special)
- towers and columns (special)	- blowers
	- plates
	- baghouse equipment
	- motors
	- conveyors
	- hoppers
	- casting machines (special)

Source: Canada, Department of Energy, Mines and Resources, Mining Association/Energy, Mines and Resources Task Force "Canadian Content of Equipment Currently in Use in Mining Operations in Canada", Mineral Policy Sector Internal Report, MRI 79/6 (mimeo: September 1979).

Table B2

SELECTED IMPORTS OF MINING-RELATED MACHINERY, 1976-1984
($ thousand)

Commodity	1976	1980	1984
Conveyors	9,143	27,150	27,106
Conveyors (parts)	15,079	35,058	42,400
Excavator cranes	157,006	144,900	153,649
Excavator (parts)	44,484	88,269	55,862
Excavating machinery	30,471	34,729	31,610
Front-end loaders	143,249	257,606	269,700
Underground loaders	18,285	22,340	28,600
Crushing & milling machinery	25,394	31,753	22,449
Quarrying machinery	34,001	91,189	76,500
Ore processing machinery	26,068	24,084	24,288
Off-highway trucks	24,591	54,888	66,462
Rock drills	14,454	40,843	16,979
Rock drill (parts)	23,302	40,843	36,971
Rock drill bits	30,877	90,566	84,800
Earth drilling machinery	17,302	31,624	23,118
Total - mining related machinery	613,705	1,016,202	960,494

Source: Statistics Canada, Imports by Commodity, Bulletin 65-007.

APPENDIX C: CANMET'S RESEARCH PROGRAMS - 1985/86

Research Program	Approximate 85/86 Budget
Explosives research	$684,000
Mining methods and equipment - emphasis on continuous operations and automation	$730,000
Rock mechanics - emphasis on ground control, particularly rockbursts	$1.4 million
Mine Environment - dust, diesel emissions, noise, vibration and radiation problems	$3.8 million
Coal Mining West - surface-mining equipment and technologies for productivity improvement	$760,000
Coal Mining East - mechanization and automation for improvements in safety and productivity	$1.6 million
Beneficiation - Metallic - computer methodology for circuit design and operation of improved mathematical models of comminution and flotation	$1.5 million
Beneficiation - Industrial Minerals - comminution technology improvements - energy conservation - p duct quality improvement	$1.8 million
Ceramics - solid electrolytes for energy storage and conversion - semiconductors for photoelectrical and catalytic processes - wear and corrosion applications	$1.4 million
Biotechnology - bioleaching of low grade ores - control of biological impact on operations - communication and technology transfer in biotechnology	$360,000

Research Program	Approximate 85/86 Budget
Extractive metallurgy - hydrometallurgy - aqueous and fused salt lead electrolysis - chloride processes for treating sulphide ores - increased recoveries of gold - improved purity of copper products	$3.6 million (over half of the budget is from the Mineral Development Agreements; almost two thirds will be contracted out)
Environmental Controls - liquid and gaseous effluents	$1 million
National Uranium Tailings Research Program - studies can be extrapolated to deal with problems of acid-generating base metals tailings and potash tailings	$2.7 million
Metallurgy - Casting Processes and Alloys - production of special alloys for research purposes - degradable mould and core sand binders - electroslag casting - graviety permanent mould casting - low pressure disposable mould casting - zinc aluminum casting - rapid solidification technology (RST) - ultra-clean steels - continuous temperature measurement of molter metal - computer-aided casting design - technology transfer: mobile foundry, workshops	$1.5 million
Metal-Working Technologies - rolling technology - direct rolling of continuously cost steel - fibre-reinforced, bimetallic, and clad metals - formability and processing of sheet steels - manufacturing technology - flat rolling, sheet metal forming, forging, extrusion and drawing	$864,000

Research Program	Approximate 85/86 Budget
Weld Process Development - welding processes, such as narrow gaps welding etc., for reactor vessels, arctic shipping and offshore rigs - modelling or simulation of metallurgical processes such as continuous casting, hot working and welding - evaluation of weldability, e.g. of new steel compositions - improvement of fracture resistance	$980,000 (of which more than 2/3 comes from energy R&D funding)
Nondestructive Evaluation of Materials and Structure - metallurgical applications such as remote sensing of defects in hot steel slab, bloom, and plate products - assessment of acoustic emission and ultrasonic transducer arrays to monitor fatigue crack growth	$1 million (over half from Energy R&D funding - pipeline related
Microstructure and Properties of Engineering Materials - microalloy steel - cast nonferrous alloys - wrought nonferrous alloys advanced materials, e.g. rapid solidification technology, laser surface treatment, engineering ceramics, ultra-fine filamentary composites	$1.4 million
Control and Prevention of Corrosion and Erosion - mechanisms of corrosion in stainless steel - materials selection for minimization of corrosion - weld-related corrosion - protective coatings in high-temperature application	$1.5 million (half from energy R&D funding - with emphasis on oil and gas production and transportation coal combustion, marine and offshore structures
Development and Application of Advanced Instrumentation - CANMET portable X-ray stress diffractometer - advanced materials and methods - Microbeam and X-ray analysis	$547,000
Materials Failure Control and Analysis - mechanical properties and stress analysis of metals	$1.1 million (mostly energy-related & funded)

The CANMET programs above are not entirely intramural. They include a growing proportion of contracts with industry and university researchers.

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